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CRYSTAL CHEMISTRY OF THE PHOSPHATES, ARSE- NATES AND VANADATES OF THE TYPE $A_2XO_4(Z)$

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I. INTRODUCTION

1. STATEMENT OF PROBLEM

This investigation was undertaken to determine the extent to which minerals of a single chemical type are related, and whether their chemical and physical properties permit their arrangement in a simple classification. The chemical type chosen for this research is expressed by the general formula $A_2XO_4(Z)$, which assumed no prior knowledge of the atomic structure. Another formula $(AZ)(AXO_4)$, in use in current literature, presupposes a clear perception of the structure, which, the writer believes, has not been adequately demonstrated.

2. CRITERIA FOR MINERALOGICAL CLASSIFICATION

A. Chemical Criteria. The new approach to the crystallochemical classification between species has been here attempted (Berman, 1937). When minerals are assumed to belong to a chemical type, it implies that their crystal structures may be related through similarities in the relative numbers and sizes of the atoms, the type of bonding between them, and their polarization properties (Stillwell, 1938). In simple chemical compounds, these properties are well known, since many structural analyses

have been made (Stillwell, 1938). However, in the type $A_2XO_4(Z)$, little is known concerning their structure because of their complexity. Nevertheless, it is possible to recognize certain fundamental structural properties which must belong to all minerals of this type.

The minerals of the type $A_2XO_4(Z)$ may be divided into two families, one with a general formula $AAXO_4(Z)$, the other $ABXO_4(Z)$. This implies, in the first formula, that the two A positions are equivalent and must, therefore, be occupied either by identical atoms or by unlike atoms whose ionic radii are similar in size and may therefore substitute for each other. When these positions are occupied by identical atoms, simpler compounds are formed, e.g. libethenite $Cu_2PO_4(OH)$ which is typical of a simple salt of this type. If the positions are occupied by different atoms similar in size, a series usually results in which the ratio between the two atoms is variable, e.g. triplite $(Fe, Mn)_2PO_4(OH)$.

In this paper, those minerals forming mixed crystals are said to be isomorphous, using the term in its restricted and classical sense (in Berman, 1937). Further examples of this relationship will be seen under the discussion of the sarkinite group.

The positions AA , assumed to be equivalent in the family $AAXO_4(Z)$, become non-equivalent in the family $ABXO_4(Z)$. The AB positions are occupied by unlike atoms whose ionic radii are different, and therefore form double salts in which the ratio between these atoms closely approaches 1:1, e.g. adelite $CaMgAsO_4(OH)$.

These cation positions AA or AB are not necessarily occupied by atoms of equal valence, but the sum of such valences equals four in the phosphates, arsenates, vanadates and sulphates and six in the silicates. This is shown in adelite $Ca^{++}Mg^{++}AsO_4(OH)$, durangite $Na^+Al^{+++}AsO_4(OH)$ and andalusite $Al^{+++}Al^{+++}SiO_4(O)$.

The major division within a chemical type is the family, which is again based on chemistry. The individual species comprising the families do not necessarily form isomorphous series with each other, but they are united by ties of similar cell size, cell edge lengths, axial ratios, optical, chemical and physical properties. The minerals whose properties show this similarity may be said to be *homologous*. This term, in mineralogical classifications, should be restricted to the general relationships between families or groups, not to the more intimate relationships between species or series.

The family itself may be further divided into groups and species on the basis of crystallography and other physical properties.

In the classification which is given below, each family $AAXO_4(Z)$ and $ABXO_4(Z)$ contains three crystallographic sections, orthorhombic, monoclinic and triclinic. For purposes of clarity and to avoid repetition, the

discussion of the groups and species will be given under their appropriate crystallographic sections. This arrangement of the discussion will also bring out certain relationships between the orthorhombic species which would otherwise be lost.

B. Crystallographic Criteria. The general crystallographic constants from the morphology and x-ray study must be in simple relation. In many cases the morphological constants do not coincide with the x-ray constants. This disagreement may lie in the adopted morphological orientation, in the choice of the unit form or both. When such discrepancies occur, the morphology is changed in this paper to conform to the

TABLE 1. CLASSIFICATION OF THE PHOSPHATES, ARSENATES AND VANADATES OF THE CHEMICAL TYPE $A_2XO_4(Z)$

Family $AAXO_4(Z)$

Orthorhombic Section

Libethenite group

Libethenite	Cu_2	PO_4	(OH)
Olivenite	Cu_2	AsO_4	(OH)
Adamite	Zn_2	AsO_4	(OH)

Monoclinic Section

Sarkinite group

Sarkinite	Mn_2	AsO_4	(OH)
Triplite	$(Mn, Fe)_2$	PO_4	(F)
Sarcopside	$(Fe, Mn, Ca)_2$	PO_4	(F)
Pseudotriplite	$(Fe, Mn)_2$	PO_4	(F)
Triploidite	$(Mn, Fe)_2$	PO_4	(OH)
Wagnerite	Mg_2	$(Ca, P)O_4$	(F)

Triclinic Section

Tarbuttite	Zn_2	PO_4	(OH)
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Family $ABXO_4(Z)$

Orthorhombic Section

Adelite group

Adelite	$MgCa$	AsO_4	(OH, F)
Higginsite	$CuCa$	AsO_4	(OH)
Calciovolborthite	$CuCa$	VO_4	(OH)
Austinite	$ZnCa$	AsO_4	(OH)
Duftite	$CuPb$	AsO_4	(OH)
Descloizite	$(Cu, Zn)Pb$	VO_4	(OH)
Araeoxen	$ZnPb$	$(V, As)O_4$	(OH)
Pyrobelonite	$MnPb$	VO_4	(OH)
Brackebuschite	$PbMn$	VO_4	(OH)

Monoclinic Section

Tilasite	$MgCa$	AsO_4	(F, OH)
Durangite	$NaAl$	AsO_4	(F)
Herderite	$CaBe$	PO_4	(OH, F)

Triclinic Section

Amblygonite	$(Li, Na)Al$	PO_4	(F, OH)
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structural crystallography. This change is commonly advantageous since the new morphology usually gives simpler indices. A full discussion of the orientation adopted here will be given later.

These crystallographic constants, when properly adjusted, may then be used as a basis for arranging the species in an orderly manner within their crystallographic sections.

The major criteria for a mineralogical classification have now been given. It is, therefore, advisable at this point, before discussing the details of the data, to present the suggested classification. This is given in Table 1.

This classification may be compared with that of Dana (1892). The major outline of both classifications is essentially the same, since both are based on the same principles. Because Dana did not recognize the family, as used here, his arrangement is somewhat different. This is due in large part to the fact that the new x -ray technique was not available to him.

The classifications given by Hintze and by Doelter are essentially the same as Dana's with more emphasis placed on chemistry, which accounts for the somewhat different arrangement.

II. DATA FOR THE TYPE $A_2XO_4(Z)$

1. CHEMISTRY

A. Phosphates, arsenates, vanadates. No new chemical analyses have been made for this study with the exception of wagnerite, which will be discussed in its proper place. The chemical composition of the members of the type is well known and generally accepted so that a detailed description of each species from this point of view is unnecessary.

B. Sulphates. Two sulphates, lanarkite, Pb_2SO_5 , and dolerophanite, Cu_2SO_5 , may be considered as possible members of the chemical type, since their formulae may equally well be written $Pb_2SO_4(O)$ and $Cu_2SO_4(O)$, respectively. The x -ray examination of these two minerals in conjunction with their chemical and physical properties shows no relationship with the corresponding properties of any members of the type. The study of these minerals has already been published by Richmond and Wolfe (1938, 1939). The following table summarizes these results.

	<i>Lanarkite</i>	<i>Dolerophanite</i>
Comp.	Pb_2SO_5	Cu_2SO_5
a_0	13.73	9.39
b_0	5.68	6.30
c_0	7.07	7.62
$a_0:b_0:c_0$	2.417:1:1.245; $\beta = 116^\circ 13'$	1.490:1:1.209; $\beta = 122^\circ 41\frac{1}{2}'$
V_0	494	380

	<i>Lanarkite</i>	<i>Dolerophanite</i>
Space Group	C_{2h}^3-C2/m	C_{2h}^3-C2/m
H	2-2.5	3
D	6.92	4.17
Optics		
X	1.928	1.715
Y	2.007; $Y=b$	1.820; $Y=b$
Z	2.036; $Z \wedge c = 30^\circ$	1.880; $Z \wedge c = 10^\circ$

A comparison of these properties with those shown in Table 4 under the tilasite group indicates that the two minerals, lanarkite and dolerophanite, are more nearly related to members of this group than to the other monoclinic minerals. An examination of the powder photographs (Plate I) of these minerals and those of members of the tilasite group shows no similarity.

From the above evidence it may therefore be concluded that lanarkite and dolerophanite are not members of the type.

C. Silicates. Three aluminum silicates, andalusite, sillimanite and cyanite, of the composition Al_2SiO_5 , sphene $CaTiSiO_5$, and datolite $CaBSiO_5$ may be considered as possible members of the type.

The aluminum silicates are all closely related to each other, and andalusite and sillimanite are structurally similar to members of the libethinite and adelite groups, respectively. The following table summarizes the results of various investigations (Taylor, 1928; St. Náray Szabo, Taylor and Jackson, 1928; Taylor, 1929).

	<i>Andalusite</i>	<i>Sillimanite</i>	<i>Cyanite</i>
Comp.	$Al_2SiO_4(O)$	$Al_2SiO_4(O)$	$Al_2SiO_4(O)$
a_0	7.76	7.43	7.09 $\alpha = 90^\circ 05\frac{1}{2}'$
b_0	7.90	7.58	7.72 $\beta = 101^\circ 02'$
c_0	5.56	5.74	5.56 $\gamma = 105^\circ 44\frac{1}{2}'$
$a_0:b_0:c_0$	0.982:1:0.703	0.980:1:0.757	0.919:1:0.720
V_0	341	323	
No. of Mol.	4	4	4
Space Group	$D_{2h}^{12}-Pnnm$	$D_{2h}^{16}-Pnma$	$C_3^1-P\bar{1}$
H	7.5	6-7	5-7.25
D	3.16-3.20	3.23-3.24	3.56-3.67
Opt. Orient.	$Y=b; Z=a$	$X=b; Z=c$	$X=\sim \perp \{001\}; Z \wedge c = -30^\circ$
n_X	1.634	1.659	1.712
n_Y	1.639	1.660	1.720
n_Z	1.643	1.680	1.728
Sign	neg.	pos.	pos./neg.

A comparison of these properties with those given in Table 3 shows similarity in the ratio of the cell edge lengths to the libethenite group, but considerable difference in the absolute cell edge lengths which are more

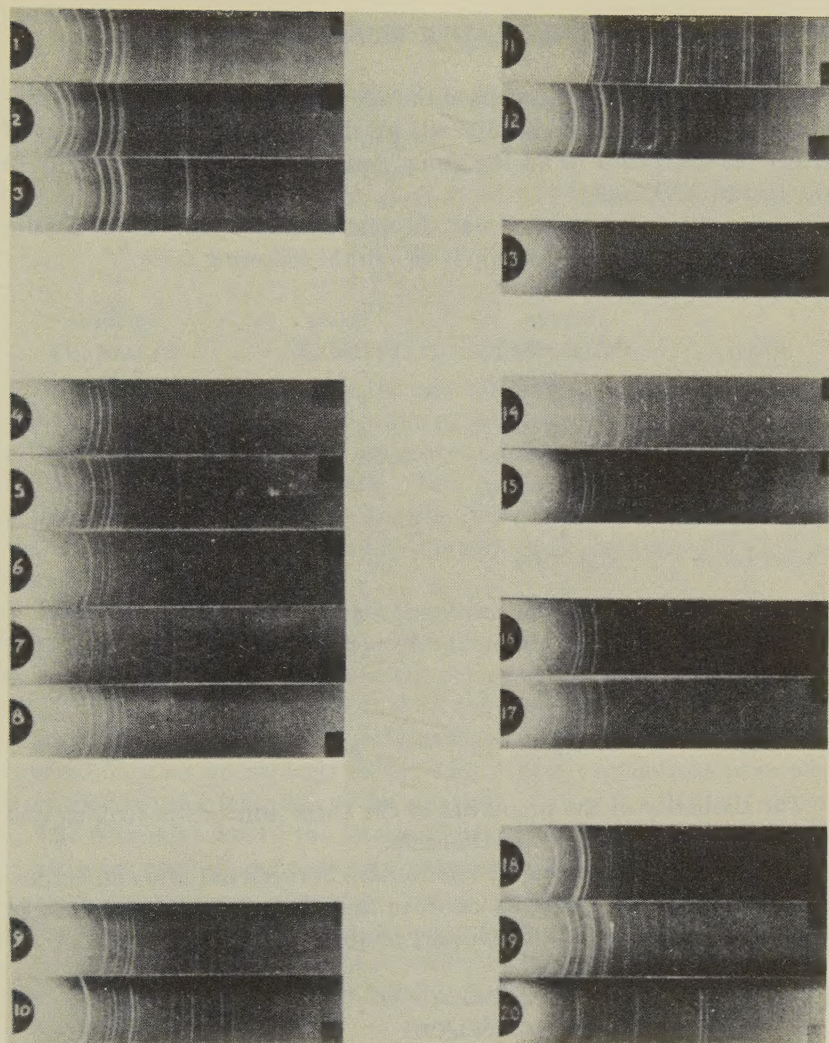


Plate I.

Powder photographs of some of the minerals of the type $A_2XO_4(Z)$

- | | |
|----------------------|-------------------|
| 1. Libethenite | 12. Dolerophanite |
| 2. Olivenite | 13. Wagnerite |
| 3. Adamite | 14. Herderite |
| 4. Higginsite | 15. Datolite |
| 5. Austinite | 16. Tilasite |
| 6. Duftite | 17. Durangite |
| 7. Descloizite | 18. Amblygonite |
| 8. Calciovolborthite | 19. Tarbuttite |
| 9. Andalusite | 20. Cyanite |
| 10. Sillimanite | |
| 11. Lanarkite | |

closely related to some members of the adelite group. On this basis it cannot be assumed that these minerals are homologous with members of either the libethenite or adelite group, but they are related generally to the family $AAXO_4(Z)$.¹

Strunz (1937) has pointed out the relationship of sphene to tilasite and durangite. This relationship is seen in the following table.

	<i>Tilasite</i>	<i>Sphene</i>	<i>Durangite</i>
Comp.	$CaMgAsO_4(F)$	$CaTiSiO_4(O)$	$NaAlAsO_4(F)$
a_0	7.56	7.43	7.30
b_0	8.95	8.70	8.46
c_0	6.66	6.55	6.53
$a_0:b_0:c_0$	0.839:1:0.750	0.854:1:0.753	0.856:1:0.772
β	120°59'	119°43'	119°22'
V_0	386	367	352
No. of Mol.	4	4	4
Space Group	C_{2h}^6-C2/a	C_{2h}^6-C2/a	$C_{2h}^6-C_2/a$
H	5	5-5.5	5
D	3.68-3.79	3.4-3.56	3.94-4.03
Opt. Orient.	$Z=b$; ext. 30°	$Y=b$; $Z/\wedge c=51^\circ$	$Y=b$; $Z/\wedge c=65^\circ$
n_X	1.640	1.900	1.634
n_Y	1.660	1.907	1.673
n_Z	1.675	2.034	1.685
Sign	neg.	pos.	neg.

The similarity of the properties of the three minerals is striking and illustrates the homologous relationship.

Strunz (1936) has shown the relationship between datolite and herderite. The remarkable similarity between the physical constants is seen in the following table and in the powder photographs of Plate I.

	<i>Datolite</i>	<i>Herderite</i>
Comp.	$CaBSiO_4(OH)$	$CaBePO_4(F, OH)$
a_0	9.64	9.80
b_0	7.62	7.68
c_0	4.82	4.80
$a_0:b_0:c_0$	1.266:1:0.633	1.276:1:0.625
β	90°09'	90°06'
V_0	352	314
No. of Mol.	4	4

¹ Machatschki (1930) states that powder photographs of berzeliite (Na, Ca_2) $Mn_2As_3O_{12}$ and calcium garnets are nearly identical. He explains this similarity on the basis of "isomorphism" between As and Si atoms. This is additional evidence that Si behaves in much the same manner as P , As and V in the XO_4 group. It is, therefore, not surprising that the silicates considered here are more or less closely related to the phosphates, arsenates and vanadates of the type.

	<i>Datolite</i>	<i>Herderite</i>
Space Group	$C_{2h}^5 - P2_1/c$	$C_{2h}^5 - P2_1/c$
H	5-5.5	5
D	2.9-3.0	3.0
Opt. Orient.	$Y=b; Z \wedge c = 1-4^\circ$	$Y=b; Z \wedge c = 3\frac{1}{2}^\circ$
n_X	1.626	1.591
n_Y	1.654	1.611
n_Z	1.670	1.619
Sign	neg.	neg.

2. CRYSTALLOGRAPHY

In order to directly compare the crystallography of each species in the various crystallographic sections and to point out the relationships which exists between them, it is first necessary to reduce the orientation of each species to a comparable setting. This has been accomplished in the orthorhombic section by adopting the conventional setting $b > a > c$. In the monoclinic system, b is fixed by the symmetry, but the other axes are chosen with $a > c$.

This orientation, for many of the species, has not been adopted in the original description. These species are therefore reoriented to conform to this convention, and transformation formulae (Donnay in Peacock, 1937) are given from the original to the conventional setting. In the orthorhombic and monoclinic sections these changes, with one exception, involve only an interchange of the axes. These conventions have also been used in the orientation of the unit cell.

The determination of the lattice constants derived from x -ray study constitutes most of the new data presented here. Therefore, a comprehensive description of the x -ray crystallography of each species will be given and the relation to the crystal morphology stated.

A. Orthorhombic Section. The minerals in this section are nine in number, three belonging to the family $AAXO_4(Z)$ and six to the family $ABXO_4(Z)$.

The crystallography of these minerals as a whole is characterized by similarity of absolute cell edge lengths and axial ratios; on the other hand, there are certain systematic differences in these constants which may be arranged to exhibit a certain definite continuity. This is shown in Table 2, where the arrangement of the species follows very closely a slight differential increase in the lengths of a_0 and b_0 ; c_0 remains constant throughout the entire sequence and shows a maximum difference of only 3%. This systematic change in the absolute cell edge lengths is reflected in a corresponding change in the volume and axial ratios of the unit cell. There is a definite interruption in this continuity between adamite and adelite. This interruption occurs at the transition from simple to double compounds, and is accompanied by an ap-

TABLE 2. SUMMARY OF THE LATTICE CONSTANTS OF THE LIBETHENITE AND ADELITE GROUPS

	1	2		3	4	5	6	7
	Composition	Cell edge lengths		Axial Ratio	Vol.	Ionic radii of cations	Ionic sum	a_0/c_0
		a_0	b_0					
<i>Libethenite Group</i>								
Libethenite	$\text{Cu}_3\text{PO}_4(\text{OH})$	8.08	8.43	0.958:1:0.700	401	.80 (Est.)	1.60	1.37
Olivenite	$\text{Cu}_2\text{AsO}_4(\text{OH})$	8.16	8.54	0.955:1:0.686	408	.80	1.60	1.38
Adamite	$\text{Zn}_2\text{AsO}_4(\text{OH})$	8.32	8.54	0.974:1:0.712	431	.83	1.66	1.37
<i>Adelite Group</i>								
Adelite	$\text{MgCaAsO}_4(\text{OH})$	7.43	8.85	0.840:1:0.665	387	.78, 1.06	1.84	1.26
Higginsite	$\text{CuCaAsO}_4(\text{OH})$	7.42	9.20	0.806:1:0.636	399	.80, 1.06	1.86	1.26
Austinite	$\text{ZnCaAsO}_4(\text{OH})$	7.43	9.00	0.826:1:0.656	394	.83, 1.06	1.89	1.26
Duftite	$\text{CuPbAsO}_4(\text{OH})$	7.50	9.12	0.822:1:0.647	404	.80, 1.32	2.12	1.27
Descloizite	$(\text{Cu, Zn})\text{PbVO}_4(\text{OH})$	7.56	9.39	0.805:1:0.643	430	.82, 1.32	2.14	1.25
Pyrobelonite	$\text{MnPbVO}_4(\text{OH})$	7.58	9.45	0.802:1:0.644	451	.91, 1.32	2.23	1.25

TABLE 3. SUMMARY OF THE CHEMICAL AND PHYSICAL PROPERTIES OF THE LIBETHENITE AND ADELITE GROUPS
Libethenite Group

Mineral Comp.	Libethenite $Cu_2PO_4(OH)$	Olivenite $Cu_2AsO_4(OH)$	Adamite $Zn_2AsO_4(OH)$
a_0	8.08	8.16	8.32
b_0	8.43	8.54	8.54
c_0	5.90	5.86	6.08
$a_0:b_0:c_0$	0.958:1:0.700	0.955:1:0.686	0.974:1:0.712
V_0	401	408	431
Ionic Sum	1.60	1.60	1.66
No. of Mol.	4	4	4
Space Group	$D_{2h}^{12}-Pnnm$	$D_2^4-P2_12_1$	$D_{2h}^{12}-Pnnm$
H	3	3	3.5
D	3.6-3.8	4.1-4.4	4.34-4.35
Opt. Orient.	$Y=c, X=b$	$Y=c, X=b$	$Y=c, X=b$
nX	1.702	1.772	1.708
nY	1.745	1.810	1.744
nZ	1.789	1.863	1.773
Sign	Negative	Positive	Negative

Mineral Comp.	Adelite $MgCaAsO_4(OH)$	Higginsite $CuCaAsO_4(OH)$	Austinite $ZnCaAsO_4(OH)$	Dufite $CuPbAsO_4(OH)$	Descloizite $(Cu, Zn)PbVO_4(OH)$	Pyrobelonite $MnPbVO_4(OH)$
a_0	7.43	7.42	7.43	7.50	7.56	7.84
b_0	8.85	9.20	9.00	9.12	9.12	9.45
c_0	5.88	5.85	5.90	5.90	6.05	6.09
$a_0:b_0:c_0$	0.840:1:0.665	0.806:1:0.636	0.826:1:0.656	0.822:1:0.647	0.805:1:0.643	0.802:1:0.644
V_0	387	399	394	404	432	451
Ionic Sum	1.84	1.86	1.89	2.12	2.14	2.23
No. of Mol.	4	4	4	4	4	4
Space Group	$D_{2h}^{16}-Pnam$	$D_{2h}^{16}-Pnam$	$D_2^4-P2_12_1$	D_{2h}^8-Pnma	$D_{2h}^{16}-Pnma$	$D_{2h}^{16}-Pnam$
H	—	4.5	4	3	3.5	3.5
D	3.71-3.76	4.33	4.12	6.19	5.9-6.2	5.38
Opt. Orient.	—	$Y=a, X=b$	$Y=c, X=a$	—	$Y=b, X=a$	$Y=c, X=a$
nX	—	1.800	1.759	2.06	2.185	2.32
nY	—	1.836	1.763	2.08	2.265	2.36
nZ	—	1.846	1.783	2.09	2.35	2.37
Sign	—	Negative	Positive	Negative	Positive	Negative

preciable change in the absolute cell edge lengths. In the libethenite groups there is an increase of 1–2% in the absolute lengths a_0 and b_0 , but in the transition from the libethenite $AA(XO_4)Z$ to the adelite group $AB(XO_4)Z$; a_0 decreases 10% and b_0 increases 4%. In the adelite group the orderly increase of about 1% for a_0 and b_0 is again apparent. This break in the sequence between the two groups is also reflected in the change in the ratio of $a_0:c_0$ from 1.37 to 1.26.

These significant crystallographic and chemical changes are accompanied and, as will be pointed out, are caused by a systematic increase in the sum of the ionic radii of the cations AA or AB .

The orthorhombic section may, therefore, be divided into two groups (Table 2), on the basis of (1) change from simple to double salts, (2) relatively large change in the absolute cell edge lengths and axial ratios, and (3) abrupt change in the sum of the ionic radii of the cations.

The physical properties, hardness and density, vary somewhat, as would be expected from the chemical composition. This variation is shown in Table 3.

The habit of the crystals in the libethenite group is remarkably constant, varying little from short prismatic with simple terminations. The minerals of the adelite group vary from short prismatic to a needle-like habit having a considerably more complex form pattern.

The optical properties of the libethenite group are consistent with each other, but in the adelite group there is no correspondence. This lack of correspondence is due to the fact that optical properties are sensitive to slight chemical changes. In the adelite group, these chemical changes are relatively great. The optical properties are given in Table 3.

(a) **LIBETHENITE GROUP.** This group is composed of three minerals, libethenite, olivenite and adamite. They are all simple salts $AAXO_4(Z)$ forming crystals of similar habit and have similar cell edge lengths and an $a_0:c_0$ ratio of 1.37.

Libethenite and adamite. Strunz (1936) determined the lattice constants and space group of libethenite and adamite. These results are:

	<i>Libethenite</i>	<i>Adamite</i>
a_0	8.08	8.32
b_0	8.43	8.54
c_0	5.90	6.08
$a_0:b_0:c_0$	0.958:1:0.700	0.974:1:0.712
$a:b:c$	0.960:1:0.703 (Melczer, 1904)	0.9770:1:0.7124 (morphology) (Ungemach, 1921)
Space Group	$D_{2h}^{12} - Pnnm$	$D_{2h}^{12} - Pnnm$

Strunz states that these minerals may belong to the space group $Pmmn$ or $Pmmm$. His evidence is based on powder photographs and is not sufficient to place them definitely in any one of these space groups.

The cell formula of libethenite is $4[Cu_2PO_4(OH)]$ derived from the following table:

Analysis		Proportions		No. of atoms per unit cell	
Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
CuO	66.42	0.838	Cu 0.838	7.97	8
P ₂ O ₅	29.31	0.207	P 0.414	3.94	4
H ₂ O	3.74	0.210	H 0.420	3.99	4
			O 2.083	19.82	20
	99.47				
	100.00				

Specific gravity: measured 3.94, calculated 3.94.

Analysis of libethenite from Coquimbo, Chile; analyst Field (1875).

The cell formula of adamite is $4[Zn_2AsO_4(OH)]$ determined from the following table:

Analysis		Proportions		No. of atoms per unit cell	
		Molecular	Atomic	Actual	Theory
ZnO	56.98	0.701	Zn 0.701	7.97	8
As ₂ O ₅	39.80	0.181	As 0.362	4.12	4
H ₂ O (diff.)	3.22	0.178	H 0.356	4.05	4
			O 1.854	21.10	20
	100.00				

Specific gravity: measured 4.35, calculated 4.39.

Analysis of adamite from Island of Thasos; analyst Rosický (1908).

Olivenite. Heritsch (1937) worked out the lattice constants, space groups and structure of olivenite. The writer, working at the same time, agrees with Heritsch's determination of the lattice constants but not with the space group. These constants are:

	<i>Heritsch</i>	<i>Richmond</i>
a_0	8.20	8.16
b_0	8.62	8.54
c_0	5.94	5.86
$a_0:b_0:c_0$	0.963:1:0.689	0.955:1:0.686
$a:b:c$	0.9485:1:0.6810	(morphology)
Space group	$D_{2h}^{12} - Pnnm$	$D_2^4 - P2_12_12_1$

Transformation Goldschmidt (1897)—Heritsch and Richmond 010/100/001; an interchange of the a - and b -axes.

The unit cell of olivenite contains $4[Cu_2AsO_4(OH)]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
CuO	55.40	55.80	0.703	Cu 0.706	7.65	8
FeO	0.25	0.25	0.003			
As ₂ O ₅	40.05	40.35	0.176			
P ₂ O ₅	0.06	0.06	0.001	As 0.354	3.84	4
H ₂ O	3.39	3.54	0.197	H 0.394	4.28	4
				O 1.788	19.40	20
	99.15	100.00				

Specific gravity: measured 4.378, calculated 4.58.

Analysis of olivenite from American Eagle Mine, Tintic, Utah; analyst Hillebrand (1886).

The writer took Weissenberg photographs about $c[001]$ and $a[100]$ and from the various layer-line reciprocal lattice projections determined space group criteria which definitely assigned olivenite to the space group D_2^4 . This is the one symmetry class which has a unique solution with Weissenberg technique. The following reflections were present on the projections:

(hkl) with all present
 ($h00$) with h even
 ($0k0$) with k even
 ($00l$) with l even

This permits of only one space group D_2^4 , which corresponds to the disphenoidal crystal class.

Believing that there should be some morphological evidence of the space group determined from the x -ray study, specimens of olivenite from Tintic, Utah, were examined for suitable crystals for goniometric measurement. Excellent crystals were found which were terminated by the unit pyramid and several domes.

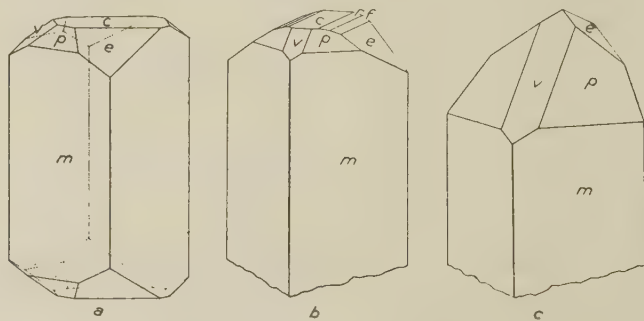


FIG. 1. Crystals of olivenite from Tintic, Utah, illustrating (a) the hemimorphic character of the mineral; (b) a typical habit with the new form $r\{012\}$, (c) an unusual habit with strong development of (111) and $(1\bar{1}1)$.

The distribution of the faces of the unit pyramid upon the numerous measured crystals indicates that olivenite is hemimorphic about the a -axis. In order to retain an orientation similar to that of libethenite and adamite, this hemimorphic axis has not been transferred to the conventional c -axis.

Figure 1a shows the usual development of the common forms with the faces (111) and ($\bar{1}\bar{1}1$), the only faces of the unit pyramid present; this is regarded as the unit hemipyramid. This condition was found on 25 measured crystals. On two crystals only, shown in Fig. 1c, there were, in addition, small faces of the unit negative hemipyramid ($\bar{1}11$) and ($1\bar{1}1$).

With regard to the other terminal forms, $V\{101\}$ is usually prominent and $V'\{\bar{1}01\}$ a small face; $e\{011\}$ and $e'\{0\bar{1}1\}$ are equally developed. One new form, $r\{012\}$, occurred on 5 crystals as a small, brilliant face (Fig. 1b) and on the gnomonic projection appeared in good position. The following table gives the measured mean, average mean, and calculated ϕ and ρ of the new form:

Number of faces	Measured mean		Average mean		Calculated	
	ϕ	ρ	ϕ	ρ	ϕ	ρ
7	$-0^\circ08' - +0^\circ08'$		$18^\circ53' - 19^\circ02'$		$-0^\circ01' \quad 18^\circ58'$	
					$0^\circ00' \quad 18^\circ48'$	

The hemimorphic character of the crystals of olivenite is thus established by the morphology. The distribution of the pyramid planes which would satisfy the disphenoidal symmetry called for by the x -ray study was not found on a single crystal. However, by analogy with austinite, a member of the adelite group belonging to the space group D_2^4 , there is still further evidence that olivenite is disphenoidal. A comparison of the reciprocal lattice projections of austinite and olivenite shows nearly exact spot-for-spot coincidence, and the morphology of austinite is definitely disphenoidal.

At the present time, therefore, olivenite must be considered disphenoidal on the basis of the x -ray study. The discrepancy which exists between this study and the morphology must be left for future examination.

(b) ADELITE GROUP. This group contains six minerals, adelite, higginsite, austinite, duftite, descloizite, and pyrobelonite. The group as a whole has similar but increasing cell edge lengths with an $a_0:c_0$ ratio of 1.26. They are all double salts $ABXO_4(Z)$. In general, they are prismatic, varying from a short stubby habit to a needle-like form.

Adelite. The original description of adelite by Sjögren (1894) was made on material from Jakobsberg, Sweden. Aminoff (1933) re-examined the type material and found that Sjögren had measured pyroxene crystals, in error, thinking they were adelite. This was proved both by crystallographic data and by powder photographs. Therefore, the crystallograph-

ic data given by Doelter (1914) and Hintze (1931) are not those of adelite but those of a pyroxene.

Aminoff studied anew the morphology of adelite crystals and determined the lattice constants but not the space group. He did not determine all the physical properties shown in Table 3. The orientation of Aminoff's unit cell is not in accordance with the conventional setting adopted here. His lattice constants are:

$$\begin{aligned} a_0 &= 7.43 & a_0:b_0:c_0 &= 0.840^8:1:0.665 \\ b_0 &= 8.85 & a:b:c &= 0.8294:1:0.6650 \text{ (morphology)} \\ c_0 &= 5.88 \end{aligned}$$

Transformation Aminoff-Richmond 010/100/001; an interchange of *a*- and *b*-axes.

The unit cell formula of adelite is $4[\text{CaMgAsO}_4(\text{OH},\text{F})]$ determined from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
CaO	23.43	23.46	0.418	Ca 0.418	3.76	4
MgO	17.10	17.12	0.425	Mg 0.425	3.79	4
MnO	4.38	4.38	0.062			
PbO	0.17	0.17	0.000			
P ₂ O ₅	3.01	3.01	0.021	P 0.042	4.05	4
As ₂ O ₅	47.40	47.40	0.206	As 0.412		
Cl	0.31	0.31	0.001	Cl 0.001	3.98	4
F	1.44	1.44	0.076	F 0.076		
H ₂ O	3.33	3.33	0.185	H 0.370	18.92	20
				O 2.123		
	100.57	100.62				
O = Cl ₂ + F ₂	.62	.62	0.040			
	99.89	100.00				

Specific gravity: measured 3.80, calculated 3.79.

Analysis of adelite from Långban; analyst R. Blix in Aminoff (1933).

Higginsite. The x-ray study of this mineral was made on a crystal several millimeters in size. Due to the relatively large size of the crystal, the results obtained are only accurate to approximately $1\frac{1}{2}\%$.

The constants derived from the measurements and calculations of the Weissenberg photographs give:

$$\begin{aligned} a_0 &= 7.42 & a_0:b_0:c_0 &= 0.806:1:0.636 \\ b_0 &= 9.20 & a:b:c &= 0.8010:1:0.636 \text{ (morphology)} \\ c_0 &= 5.85 \end{aligned}$$

Transformation Palache-Richmond 010/ $\frac{1}{2}$ 00/001; an interchange of the *a*- and *b*-axes with the *b*-axis halved.

The space group is D_{2h}^5 - $Pmam$ determined from the following reflections:

(hkl) with all present
 ($0kl$) with all present
 ($h0l$) with h even
 ($h\bar{k}0$) with all present

The unit cell formula is $4[CuCaAsO_4(OH)]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
Cu	28.67	29.83	0.375	Cu 0.375	3.94	4
CaO	20.83	21.67	0.387	Ca 0.387	4.06	4
As ₂ O ₅	41.23	42.90	0.187	As 0.374	4.17	4
V ₂ O ₅	1.97	2.05	0.011	V 0.022		
H ₂ O	3.41	3.55	0.198	H 0.396	4.16	4
Fe ₂ O ₃	0.48			O 1.950	20.45	20
MnO	2.84					
Gangue	0.86					
	100.29	100.00				

Specific gravity: measured 4.33, calculated 4.34.

Analysis of higginsite, Bisbee, Arizona; analyst E. V. Shannon (1920).

Palache (in Palache and Shannon, 1920) pointed out the relationship of higginsite to descloizite and olivenite. He recognized the similarity between these minerals on the basis of their axial ratios, but a closer examination of his data in connection with the x -ray study shows that higginsite is more closely related to descloizite than to olivenite.

The setting chosen by Palache does not conform to the conventional position, and his unit form is not in agreement with that obtained from the x -ray study. The choice of the unit form derived from the x -ray study gives simpler indices and is for this reason preferable.

Austinite. Staples (1935) described the morphology of austinite and showed its disphenoidal character. The x -ray study confirmed this symmetry through the reflections on the Weissenberg photographs, which are:

(hkl) with all present
 ($h00$) with h even
 ($0k0$) with k even
 ($00l$) with l even

The lattice constants derived from the measurements and calculation of the Weissenberg photographs are:

$$\begin{aligned}
 a_0 &= 7.43 & a_0:b_0:c_0 &= 0.826:1:0.656 \\
 b_0 &= 9.00 & a:b:c &= 0.832:1:0.657 \text{ (morphology)} \\
 c_0 &= 5.90
 \end{aligned}$$

Transformation: Staples-Richmond 001/010/100; an interchange of the *a*- and *c*-axes.

The unit cell formula is $4[\text{CaZnAsO}_4(\text{OH})]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
CaO	19.2	19.57	0.349	Ca 0.349	3.43	4
ZnO	32.5	33.13	0.406	Zn 0.406	3.99	4
As ₂ O ₅	42.7	43.54	0.190	As 0.380	3.74	4
P ₂ O ₅	0.1	0.10		H 0.412	4.05	4
H ₂ O	3.6	3.66	0.206	O 1.911	18.80	20
Residue	2.4					
	100.5	100.00				

Specific gravity: measured, 4.12 (ca); calculated 4.37.

Analysis of austinite from Gold Hill, Utah; analyst R. B. Ellestad (1933).

Duftite. The morphology of duftite is unknown because the crystals are poorly developed with faces lacking sufficient luster to give adequate reflections. The habit is prismatic and terminated only by (011).

The lattice constants derived from Weissenberg photographs are:

$$\begin{aligned}
 a_0 &= 7.50 & a_0:b_0:c_0 &= 0.822:1:0.647 \\
 b_0 &= 9.12 & \text{No morphology} \\
 c_0 &= 5.90
 \end{aligned}$$

This is the first time the axial ratio has been given.

The space group is, tentatively, D_{2h}^6 -*Pnan*. The first layer-line photograph about [001] is weak and gives (*hkl*) with *h*+*k* even, which with reflections from the zero layer-line photographs give inconsistent criteria. If it is assumed that the missing spectra on the first layer-line photograph are due either to the faintness of the film or structural arrangement, the reflections are then as follows and give the above space group:

(*hkl*) with all present
 (*h0l*) with *h* even
 (*0kl*) with *k*+*l* even
 (*hk0*) with *h*+*k* even
 (*00l*) with *l* even
 (*0k0*) with *k* even

The unit cell formula is $4[\text{CuPbAsO}_4(\text{OH})]$ determined from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
PbO	50.10	50.48	0.226	Pb 0.226	3.62	4
CaO	0.75	0.75	0.013	Ca 0.013		
ZnO	0.46	0.46	0.006	Zn 0.006	3.80	4
CuO	19.32	19.45	0.245	Cu 0.245		
SiO ₂	0.44					
As ₂ O ₅	26.01	26.20	0.114	As 0.228	3.45	4
H ₂ O	2.65	2.66	0.148	H 0.296	4.08	4
				O 1.208	18.30	20
	99.73	100.00				

Specific gravity: measured 6.19, calculated 6.99.

Analysis of duftite, Tsumeb; analyst, O. Pufahl (1920).

Descloizite. The lattice constants and space group of descloizite as given by Bannister (1933) are:

$$\begin{aligned}
 a_0 &= 7.56 & a_0:b_0:c_0 &= 0.805:1:0.643 \\
 b_0 &= 9.39 & a:b:c &= 0.8046:1:0.6367 \text{ (morphology)} \\
 c_0 &= 6.05
 \end{aligned}$$

Transformation: Goldschmidt (1897) and Bannister-Richmond 001/010/100; an interchange of the a - and c -axes.

The unit cell formula is $4[(\text{Cu},\text{Zn})\text{PbVO}_4(\text{OH})]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
ZnO	17.56	17.64	0.217	Zn 0.217	3.55	4
CuO	0.40	0.40	0.005	Cu 0.005		
FeO	0.07	0.07	—			
MnO	0.77	0.77	0.011	Mn 0.011	4.21	4
PbO	56.01	56.30	0.252	Pb 0.252		
P ₂ O ₅	0.30	0.30	0.002	P 0.004	3.90	4
V ₂ O ₅	21.85	21.95	0.120	V 0.240		
H ₂ O	2.57	2.57	0.143	H 0.286	4.52	4
Cl	0.27			O 1.238	19.80	20
Insoluble	0.78					
	100.58	100.00				

Specific gravity: measured 6.10, calculated 6.20.

Analysis of descloizite, Sierra de Córdoba, Argentina; analyst Rammelsberg (1880).

Descloizite series. Bannister investigated, by powder diffraction photographs, descloizite, mottramite, psittacinite, chileite, eusynchite and deschenite. He states that the photographs are identical and proposes to discard all species names except descloizite and mottramite. He suggests the name descloizite for a mixed crystal of the composition (Cu,Zn) -

$\text{PbVO}_4(\text{OH})$ in which there is less than 10% CuO and when this figure is exceeded he proposes the name *mottramite*.

In this series there is a statistical replacement of *Cu* and *Zn* in one of the non-equivalent positions AB (the other position is occupied by *Pb*) forming a mixed crystal.

Pyrobelonite. The calculations from the Weissenberg photographs give the following lattice constants:

$$\begin{aligned} a_0 &= 7.84 & a_0:b_0:c_0 &= 0.802:1:0.644 \\ b_0 &= 9.45 & a:b:c &= 0.80402:1:0.65091 \text{ (morphology)} \\ c_0 &= 6.09 \end{aligned}$$

The space group of *pyrobelonite* is D_{2h}^{16} -*Pnam* from the following reflections:

(*hkl*) with all present
(*0kl*) with *k+l* even
(*h0l*) with *h* even
(*hko*) with all present

The unit cell formula is $4[(\text{Mn}, \text{Pb})_2\text{VO}_4(\text{OH})]$ with $\text{Mn}:\text{Pb}=5:3$ determined from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
SiO_2	0.21					
PbO	48.99	49.51	0.222	Pb 0.222	3.15	3
MnO	25.01	25.26	0.357	Mn 0.357	5.08	5
FeO	0.47	0.47	0.006	Fe 0.006		
MgO	0.60	0.60	0.015	Mg 0.015		
CaO	0.79	0.79	0.014	Ca 0.014	3.21	4
V_2O_5	20.03	20.26	0.112	V 0.224		
P_2O_5	0.05	0.05	0.001	P 0.002		
H_2O	3.02	3.06	0.170	H 0.340	4.83	4
				O 1.569	22.70	20
	99.17	100.00				

Specific gravity: measured 5.377; calculated 5.39.

Analysis of *pyrobelonite*, Långban; analyst, Mauzelius (1919).

Pyrobelonite is placed provisionally in the family $\text{ABXO}_4(\text{Z})$. The ionic radii of *Mn* and *Pb*, 0.91 Å and 1.32 Å respectively, are sufficiently different in their sizes to permit the non-equivalent AB positions to be occupied by *Mn* and *Pb* with a ratio of 1:1. However, the analysis indicates that the ratio of *Mn* and *Pb* is very nearly 5:3.

The preceding table shows that the theoretical number of atoms in the unit cell is in poor agreement with those actually calculated. This is probably due to a poor analysis and the *Mn*:*Pb* ratio may then be in

error. The summary of these detailed data, together with the other physical properties, is given in Table 3.

(c) EFFECT OF THE IONS IN THE AA AND AB POSITIONS. The slight systematic changes in the physical properties that occur in the minerals of the libethenite and adelite groups may be explained on the basis of crystal chemistry.

The minerals of the libethenite group (Table 2) are simple compounds with cations Cu and Zn , and radicals PO_4 , AsO_4 and OH . The ionic radii of Cu and Zn are 0.80 Å (estimated) and 0.83 Å, respectively; there are no published values for P and As . Since the volumes of the unit cells of libethenite $Cu_2PO_4(OH)$ and olivenite $Cu_2AsO_4(OH)$ are nearly identical, it may be assumed that the ionic radii of P and As are similar in size. Because the ionic radius of Zn is greater than that of Cu and since P and As are similar in ionic size, the volume of the Zn mineral adamite $Zn_2AsO_4(OH)$ should be larger than that of the Cu minerals libethenite and olivenite. This is demonstrated from the calculated volumes of libethenite, olivenite and adamite, which are respectively 401 cubic Å, 402 cubic Å and 431 cubic Å.

In both the libethenite and adelite groups the c_0 values are approximately the same and do not show the systematic changes that are found in the a_0 and b_0 values. P and As have been shown to possess ionic radii of similar size; V probably has an ionic radius comparable to P and As .

The close relationship between the chemistry and lattice constants of these minerals is also reflected in the similarity of their other physical properties. The specific gravity, hardness, and optical properties are much the same, the greatest variation occurring in the refractive indices (Table 3).

The adelite group affords a better opportunity for examining the effect of the various atoms on the change in lattice constants and physical properties. The minerals composing this group are double salts $AB(XO_4)Z$ containing cations A and B of widely differing ionic radii. Column 5 of Table 2 gives the ionic radii of the cations. It is readily seen that, with the exception of higginsite, there is a progressive increase in the axial ratios, absolute cell edge lengths and volumes from adelite through pyrobelonite (Tables 2 and 3). These increases follow directly from the increased sum of the ionic radii of the cations. The constants of higginsite have a probable error of 1.5%, which would account for the poor agreement with the remaining members of the group.

The lattice constants of adelite, higginsite and austinite should be but slightly different because the sums of the ionic radii of the cation positions (Ca with Mg or Cu or Zn) are very nearly identical. As would be

expected, the physical properties of these minerals are similar (Table 3). However, with the introduction of *Pb* and *Mn*, the sums of whose ionic radii are nearly 10% greater than the sums of the ionic radii of the cation pairs above mentioned, the unit cells of duftite, descloizite and pyrobelonite should have lattice constants differing by approximately the same amount. An inspection of Table 3 shows this to be true. It will be noted that the absolute length b_0 is increased greatly with the introduction of *Pb* and *Mn*, indicating that these atoms may be aligned parallel to the b -axis.

The presence of *Pb* and *Mn* is also reflected in the greatly increased specific gravity and refractive indices of these minerals.

The hardness of the minerals of both the libethenite and adelite groups is remarkably constant. This may be partially explained on the assumption that the intra-atomic spacings, i.e., the distance between the atomic "boundaries," remain the same. This permits the cell volume to increase proportionally to the ionic radii of the cations but allows rupture between atoms to occur with approximately the same ease.

B. Monoclinic Section. The minerals which belong to this section are simple $AAXO_4(Z)$ and double $ABXO_4(Z)$ salts.

The intimate relationship which exists in the orthorhombic section is not as well defined in the monoclinic species. The systematic changes are not as evident although the general chemical and physical properties unite these minerals and indicate their similarity to other members of the family.

The comparison between species or series is made more easily by adopting the conventional setting $a_0 > c_0$. The monoclinic symmetry fixes the position of b_0 . In the sarkinite group, the values of b_0 of sarkinite and triplite are similar; the same is true of triploidite and wagnerite, but in the case of the latter pair b_0 is twice as great as in the former pair.

The relationship between the published morphological setting and the conventional position is correlated by a transformation formula. In all cases but sarkinite, this reorientation involves only an interchange of the a - and c -axes.

The physical properties, hardness and density, are quite constant within the various groups, which is to be expected from the similarity of the chemistry.

The optical properties of the minerals within each group are not in close agreement. This is explained by the fact that these properties are sensitive to slight changes in chemical composition. The compositions of the minerals of each group are quite different, so that no close correspondence is to be expected in these properties (Table 4).

TABLE 4. SUMMARY OF THE CHEMICAL AND PHYSICAL PROPERTIES OF THE TILASITE AND SARKINITE GROUPS, AND HERDERITE

Mineral Comp.	Tilasite Group		Herderite CaBePO ₄ (F, OH)	Sarkinite		Sarkinite Group		Wagnerite Mg ₂ (Ca, P)O ₄ (F)
	Tilasite CaMgAsO ₄ (F)	Durangite NaAlAsO ₄ (F)		Sarkinite Mn ₂ AsO ₄ (OH)	Triplite (Mn, Fe) ₂ PO ₄ (F)	Triplite (Mn, Fe) ₂ PO ₄ (OH)		
a ₀	7.56	7.30	9.80	12.71	12.03	12.24	11.93	
b ₀	8.95	8.46	7.68	6.78	6.46	13.35	12.47	
c ₀	6.66	6.53	4.80	10.20	10.03	9.88	9.44	
a ₀ :b ₀ :c ₀	0.839:1:0.750	0.856:1:0.772	1.276:1:0.625	1.874:1:1.504	1.862:1:1.553	0.917:1:0.740	0.957:1:0.757	
β	120°59'	119°22'	90°06'	108°18'	105°42'	108°14'	108°07'	
V ₀	387	352	361	835	751	1535	1334.9	
No. of Mol.	4	4	4	8	8	16	16	
Space Group	C _{2h} ⁶ -C2/c	C _{2h} ⁶ -C2/c	C _{2h} ⁶ -P2 ₁ c	C _{2h} ⁵ -P2 ₁ a	C _{2h} ⁵ -P2 ₁ /a	C _{2h} ⁶ -P2 ₁ /a	C _{2h} ⁵ -P2 ₁ /a	
H	5	5	5	4-5	4-5.5	4.5-5	5	
D	3.68-3.79	3.94-4.03	3.00	4.09-4.32	3.84	3.70	3.07	
Opt. Orient.	Z = b; ext. 30°	Y = b; Z/∧c = 65°	Y = b; Z/∧c = 3½°	Y = b; Z/∧c = 36°	Y = b; Z/∧c = 48°	Y = b; Z/∧c = 3°	Y = b; Z/∧c = 21°	
X	1.640	1.634	1.591	1.793	1.665	1.725	1.569	
Y	1.660	1.673	1.611	1.807	1.673	1.726	1.570	
Z	1.675	1.685	1.619	1.899	1.682	1.730	1.582	
Sign	Negative	Negative	Negative	Negative	Positive	Positive	Positive	

The habit is quite uniformly short prismatic with a simple form series, although the elongation is either parallel to the c - or b -axes.

(a) **TILASITE GROUP.** This group contains two minerals, tilasite and durangite, both double salts $ABXO_4(Z)$ with similar habit, axial ratios and angles, and cell edge lengths. As already pointed out, sphene is homologous with these minerals.

An examination of the lattice constants of tilasite and durangite (Table 4) indicates a rational relationship with adelite and higginsite of the

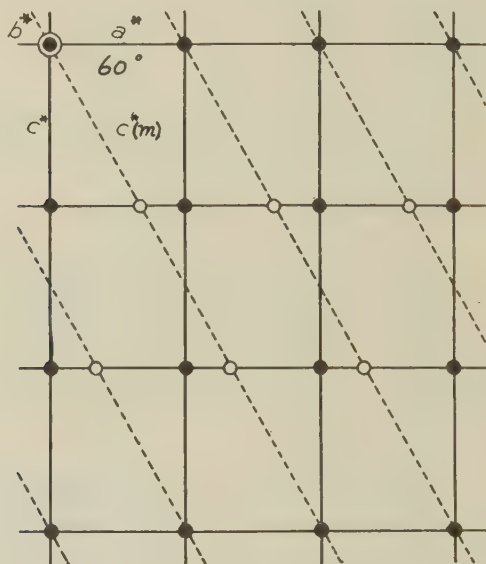


FIG. 2. A reciprocal lattice projection showing the relation of the tilasite group to the minerals of the orthorhombic section.

adelite group. This relationship is shown in Fig. 2. The position of the reciprocal lattice is the second inversion with b^* vertical. The a^* and b^* values of both the adelite and tilasite groups are approximately equal and the tilasite group c^* is $[\frac{2}{3}01]$ in the adelite group lattice. In the figure, the tilasite-group reciprocal cell is outlined in dashed lines. The transformation formula of the tilasite-group cell to the adelite-group cell is therefore $10\frac{2}{3}/010/001$ and from the adelite group to the tilasite group $10\frac{2}{3}/010/001$.

Tilasite. Strunz (1937) determined the lattice constants and space group of tilasite. In the conventional setting they are:

$$\begin{aligned}
 a_0 &= 7.56 & a_0:b_0:c_0 &= 0.839 : 1:0.750 ; \beta = 120^\circ 59' \\
 b_0 &= 8.95 & a:b:c &= 0.8454:1:0.7503; \beta = 120^\circ 59\frac{1}{2}' \text{ (morphology)} \\
 c_0 &= 6.66
 \end{aligned}$$

Transformation, Smith and Prior and Strunz-Richmond, 001/010/100; an interchange of the a - and c -axes.

Space group $C_{2h}^6 - C2/c$.

The cell formula is $4[CaMgAsO_4(F)]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
Na ₂ O	0.29	0.29	0.005			
MgO	18.22	18.20	0.451	Mg 0.451	3.99	4
CaO	25.32	25.29	0.451	Ca 0.451	4.02	4
MnO	0.16	0.16	0.002	Mn 0.002		
FeO	0.14	0.14	0.002	Fe 0.002		
As ₂ O ₅	50.91	50.86	0.221	As 0.442	3.91	4
H ₂ O	0.28	0.28		F 0.431	3.83	4
Cl	0.02	0.02		O 1.790	15.82	16
F	8.24	8.23	0.431			
	103.58	103.47				
Less O	3.47	3.47				
	100.11	100.00				

Specific gravity: measured 3.77; calculated 3.78.

Analysis of tilasite, Långban; analyst Mauzelius (1895).

Durangite. Kokkoros (1937) determined the lattice constants and space group of durangite. His data agree well with those obtained by the writer using a crystal of such large size that the accuracy of the resulting data is probably less than that obtained by Kokkoros; for this reason his values are used here.

$$\begin{aligned}
 a_0 &= 7.30 & a_0:b_0:c_0 &= 0.856 : 1:0.772 ; \beta = 119^\circ 22' \\
 b_0 &= 8.46 & a:b:c &= 0.8532:1:0.77158; \beta = 119^\circ 35' \text{ (morphology)} \\
 c_0 &= 6.53
 \end{aligned}$$

Transformation, Kokkoros and Strunz (1937)—Richmond 001/010/100; an interchange of the a - and c -axes.

Space group $C_{2h}^6 - C2/c$.

The cell formula is $4[Na(Al,Fe,Mn)AsO_4(F)]$ with Al:Fe:Mn = 6:2:1, which is derived from the following table:

	Analysis		Proportions			No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic		Actual	Theory
Li ₂ O	0.65	0.65	0.022	Li 0.044	}	4.04	4
Na ₂ O	13.06	13.10	0.211	Na 0.422			
Al ₂ O ₃	17.19	17.24	0.169	Al 0.338			
Mn ₂ O ₃	2.08	2.09	0.029	Mn 0.058	}	4.44	4
Fe ₂ O ₃	9.23	9.26	0.058	Fe 0.116			
As ₂ O ₅	53.11	53.20	0.232	As 0.464		4.03	4
F	7.67	7.69	0.405	F 0.405		3.52	4
				O 1.959		17.00	16
	102.99	103.23					
Less O	3.23	3.23					
	99.66	100.00					

Specific gravity: measured 4.07; calculated 4.11.

Analysis of durangite, Durango, Mexico; analyst Hawes (1876).

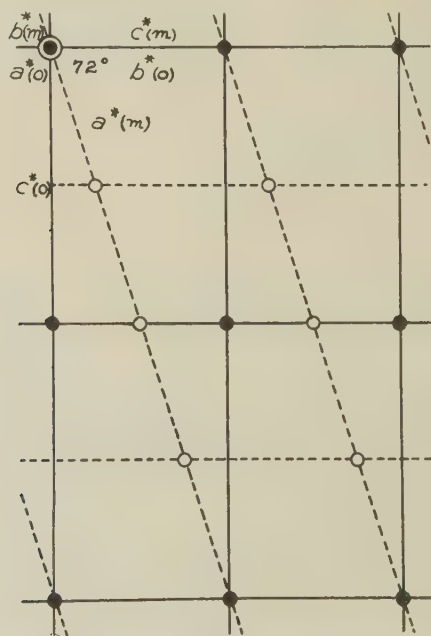


FIG. 3. A reciprocal lattice projection showing the relation of the sarkinite group to the minerals of the orthorhombic section.

(b) SARKINITE GROUP. This group contains four minerals, sarkinite, triplite, triploidite and wagnerite. They are characterized by similar cell edge lengths a_0 and b_0 , with b_0 variable. Their habits vary from prismatic parallel to the c -axis to prismatic parallel to the b -axis.

This group is related to the pyrobelonite end of the adelite group. Figure 3 shows the general relationship between the sarkinite and adelite groups; the sarkinite-group cell is outlined by dashes and is projected on the a^*-c^* plane with b^* vertical. The adelite-group cell is projected on the b^*-c^* plane with a^* vertical. With sarkinite and triplite b^* is approximately equal to the adelite-group a^* , while b^* for triploidite and wagnerite is approximately one-half the adelite-group a^* . Therefore, the volume of the cell of sarkinite and of triplite must be approximately double that of the orthorhombic cell and contains twice the number of molecules in the unit cell; and the triploidite and wagnerite cells are approximately four times as large and contain four times the molecules in the unit cell. An inspection of Tables 3 and 4 shows this relationship.

The transformation formula from the sarkinite-group cell to the adelite-group cell is $010/\frac{1}{4}01/\frac{1}{2}00$ and from the adelite-group cell to the sarkinite-group cell $002/100/01\frac{1}{2}$.

Sarkinite. The x -ray study was made on an excellent crystal approximately 0.25 mm. in the largest dimension. Rotation and Weissenberg photographs were taken about $c[001]$ and $b[010]$.

A study of the translation distances indicated that the setting adopted by Dana (1892) and Goldschmidt (1897) did not conform to the rule of the three shortest non-coplanar identity periods. If the short diagonal of the morphological cell (in the a - c plane) is taken as the new c -axis, all requirements are satisfied. The transformation from Dana and Goldschmidt to Richmond, is therefore, $\bar{1}0\bar{1}/0\bar{1}0/100$.

The elements given by Dana and Goldschmidt transformed to the new position are given below with a new angle table of the forms of sarkinite.

TABLE 5. ANGLE TABLE OF THE ACCEPTED FORMS OF SARKINITE

Sarkinite— $Mn_2AsO_4(OH)$							
$a:b:c=1.8642:1:1.5154$; $\beta=108^\circ 13\frac{1}{2}'$							
$p_0:q_0:r_0=0.8132:1.4393:1$; $\mu=71^\circ 46\frac{1}{2}'$							
$r_2:p_2:q_2=0.6948:0.5650:1$							
$p_0'=0.8562$, $q_0'=1.4393$; $x_0'=0.3037$							
Form	ϕ	ρ	ϕ_2	$\rho_2=B$	C	A	
<i>b</i> 010	0°00'	90°00'	—	0°00'	90°00'	90°00'	
<i>a</i> 100	90 00	90 00	0°00'	90 00	71 46 $\frac{1}{2}$	0 00	
<i>p</i> 120	30 45	90 00	0 00	30 45	80 48	59 15	
<i>o</i> 011	11 55	55 47	73 06 $\frac{1}{2}$	35 59	54 01	80 10	
* <i>d</i> $\bar{1}01$	—90 00	28 55	118 55	90 00	47 08 $\frac{1}{2}$	118 55	
<i>m</i> $\bar{1}11$	—21 00	57 02	118 55	38 26 $\frac{1}{2}$	64 59	107 30 $\frac{1}{2}$	
<i>n</i> $\bar{4}14$	—56 55 $\frac{1}{2}$	33 24	118 55	72 31	49 33 $\frac{1}{2}$	117 28	
<i>r</i> $\bar{1}57$	—28 15 $\frac{1}{2}$	49 24 $\frac{1}{2}$	118 55	48 01	59 38	111 04	

* $d=a$ (Goldschmidt, 1897)

The lattice constants and space group determined from the Weissenberg photographs are:

$$\begin{array}{ll} a_0 = 12.71 & a_0:b_0:c_0 = 1.874:1:1.504; \beta = 108^\circ 18' \\ b_0 = 6.78 & a:b:c = 1.864:1:1.515; \beta = 108^\circ 13\frac{1}{2}' \text{ (morphology)} \\ c_0 = 10.20 & \end{array}$$

Transformation Dana (1892) and Goldschmidt (1897)—Richmond $\bar{1}0\bar{1}/0\bar{1}0/100$.

The following reflections give the space group $C_{2h}^5-C_{21}a$:

$$\begin{array}{l} (hkl) \text{ with all present} \\ (h0l) \text{ with } h \text{ even} \\ (0k0) \text{ with } k \text{ even} \end{array}$$

The unit cell contains $8[\text{Mn}_2\text{AsO}_4(\text{OH})]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
MgO	0.38	0.38	0.001	Mg 0.001	0.02	16
CaO	1.22	1.24	0.022	Ca 0.022	0.47	
MnO	51.92	52.72	0.744	Mn 0.744	15.88	
As ₂ O ₅	41.50	42.14	0.183	As 0.366	7.82	8
H ₂ O	3.48	3.52	0.195	H 0.390	8.33	8
				O 1.877	40.10	40
	98.50	100.00				

Specific gravity: measured 4.22; calculated 4.21.

Analysis of sarkinite from Pajsberg; analyst Hamberg (1888).

From an examination of analyses of sarkinite there is good evidence that this mineral forms a partial series through the replacement of *As* by *Sb*. In fact, Igelström (1884) gives the name xanthoarsenite to a mineral containing an undetermined percentage of Sb_2O_5 .

Triplite. The morphology of triplite is unknown, since no measurable crystals have been found. Good cleavage masses are common and may, therefore, be used for *x*-ray examination. A small cleavage fragment was chosen which gave sufficiently good reflections on the cleavage faces to permit the edge between these two cleavages to be oriented as the axis of rotation. These cleavages were assumed to be pinacoidal. Rotation and Weissenberg photographs were taken about what proved to be the $b[010]$ and $c[001]$ axes, with the former perpendicular to the best cleavage (010) and the other perpendicular to (001). The results of the measurements and calculations of these photographs give the following lattice constants:

$$\begin{array}{ll} a_0 = 12.03 & a_0:b_0:c_0 = 1.862:1:1.553; \beta = 105^\circ 42' \\ b_0 = 6.46 & \text{No morphology.} \\ c_0 = 10.03 & \end{array}$$

The space group is $C_{2h}^5-P2_1/a$ from the following reflections:

(hkl) with all present
 ($h0l$) with h even
 ($0k0$) with k even

The unit cell content is $16[(Mn,Fe)_2PO_4(OH)]$ with Mn:Fe = 8:1 derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
Fe ₂ O ₃	0.40	0.40	0.003	Fe''' 0.006	0.10	16
FeO	6.68	6.69	0.093	Fe'' 0.093	1.63	
MnO	53.77	53.80	0.758	Mn 0.758	13.25	
MgO	0.31	0.31	0.008	Mg 0.008	0.14	
CaO	2.17	2.17	0.039	Ca 0.039	0.59	
P ₂ O ₅	32.20	32.23	0.227	P 0.454	7.94	8
F	7.58	7.59	0.399	F 0.399	6.98	8
				O 1.841	32.20	32
	103.58	103.19				
Less O	3.19	3.19				
	99.92	100.00				

Specific gravity: measured 3.84; calculated 3.94.

Analysis of triplite from Bagdad, Arizona; analyst F. A. Gonyer (in Hurlbut 1936).

Triplite, as has been shown, represents a series with a varying proportion of Mn:Fe. Minerals, which may be included in this series on the basis of their analyses, are pseudotriplite and sarcopside.

Triploidite. A small perfect crystal of triploidite was found in a specimen from Branchville, Connecticut. Rotation and Weissenberg photographs were taken about $b[010]$ and $c[001]$, which gave the following lattice constants:

$$\begin{aligned}
 a_0 &= 12.24 & a_0:b_0:c_0 &= 0.917:1:0.740 & ; \beta &= 108^\circ 04' \\
 b_0 &= 13.35 & a:b:c &= 0.92858:1:0.74627 & ; \beta &= 108^\circ 14' \\
 c_0 &= 9.88 & & & & \text{(morphology)}
 \end{aligned}$$

Transformation, Dana-Richmond $100/0\frac{1}{2}0/001$; a halving of the b -axis.

The space group is $C_{2h}^5-P2_1/a$ from the following reflections:

(hkl) with all present
 ($h0l$) with h even
 ($0k0$) with k even

The unit cell formula is $16[(Mn, Fe)_2PO_4(OH)]$ with Mn:Fe = 3:1 from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
FeO	14.88	14.90	0.207	Fe } 0.213	7.33	8
CaO	0.33	0.33	0.006	Ca }		
MnO	48.45	48.52	0.684	Mn 0.684	23.56	24
P ₂ O ₅	32.11	32.16	0.226	P 0.452	15.56	16
H ₂ O	4.08	4.09	0.227	H 0.454	15.63	16
				O 2.274	78.34	80
	99.85	100.00				

Specific gravity: measured 3.697; calculated 3.83.

Analysis of triploidite from Branchville, Connecticut; analyst Penfield (1878).

Wagnerite (Cryphiolite). The generally accepted formula of wagnerite was suspected to be in error on the basis of the *x*-ray study. It was found that the unit cell formula was different from that derived from the interpretation of the published analyses. A new analysis was made by F. A. Gonyer of the Harvard Mineralogical Laboratory. The details of the *x*-ray study and a new interpretation of the chemistry are given below.

The lattice constants and chemical composition of wagnerite were determined from portions of the same specimen from the type locality, Werfen, Germany. Rotation and Weissenberg photographs were taken about *c*[001] and *b*[010] axes. The results of the measurements and computations of the photographs give:

$$\begin{aligned}
 a_0 &= 11.93 & a_0:b_0:c_0 &= 0.957:1:0.757; \beta = 108^\circ 09' \\
 b_0 &= 12.47 & a:b:c &= 0.9573:1:0.7530; \beta = 108^\circ 07' \text{ (morphology)} \\
 c_0 &= 9.44
 \end{aligned}$$

Transformation, Miller (1879)—Rich 100/0 $\frac{1}{2}$ 0/001; a halving of the *b*-axis.

The halving of the morphological *b*-axis to conform to the absolute cell edge lengths materially simplifies the given indices. It is therefore suggested as the better setting.

The space group is $C_{2h}^5-P2_1/a$ determined from the following reflections:

$$\begin{aligned}
 (hkl) &\text{ with all present} \\
 (h0l) &\text{ with } h \text{ even} \\
 (0k0) &\text{ with } k \text{ even}
 \end{aligned}$$

The unit cell content was derived from the lattice constants, density (3.153, average of 4 new determinations) and the new analysis. This analysis is similar to many given in the literature, and it is therefore probable that the interpretation of the older analyses has been in error, not the analyses themselves. The older interpretation bracketed the molecular ratio of the whole of the RO constituents as shown below, using Gonyer's analysis as an example.

Specific gravity: measured 3.153; calculated 3.158.

1. Analysis of wagnerite from Werfen; analyst Gonyer.
2. Analysis calculated to 100%.
3. Molecular proportions.
4. Atomic proportions.
5. Number of atoms in the unit cell.
6. Theoretical number of atoms in the unit cell.
7. Composition of $\text{Mg}_2\text{PO}_4\text{F}$.
8. Composition of $\text{Mg}_{32}(\text{Ca}, \text{P}_{15})\text{O}_{64}\text{F}_{13}$.

Strunz (1938) includes cryphiolite as an isotype with durangite, tilasite, and sphene, changing its published orientation to bring out this relationship. This conclusion is not in accord with our findings.

Herderite. The lattice constants and space group were determined by Strunz (1936) and are:

$$\begin{aligned} a_0 &= 9.80 & a_0:b_0:c_0 &= 1.276 : 1:0.625 & ; \beta &= 90^\circ 06' \\ b_0 &= 7.68 & a : b : c &= 1.2775 : 1:0.62457 & ; \beta &= 90^\circ 06' \text{ (morphology)} \\ c_0 &= 4.80 \end{aligned}$$

Space group $C_{2h}^2 - P2_1/c$.

Transformation, Durrfeld (1909) and Strunz-Richmond 001/010/300; an interchange of the a - and c -axes with a tripling of the c -axis. Yatsevitch (1935) originally recognized the tripling of the c -axis on morphological evidence.

The unit cell formula is $4[\text{CaBePO}_4(\text{F}, \text{OH})]$, with $\text{OH}:\text{F} = 1:1$, from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
CaO	33.67	33.93	0.605	Ca 0.605	3.97	4
BeO	15.51	15.63	0.625	Be 0.625	4.10	4
P ₂ O ₅	43.74	44.05	0.310	P 0.620	4.06	4
H ₂ O	3.70	3.73	0.207	H 0.414	2.72	4
F	5.27	5.32	0.279	F 0.279	1.83	18
				O 2.841	18.62	
	101.89	102.66				
Less O	2.64	2.66				
	99.25	100.00				

Specific gravity: measured 3.00; calculated 2.96.

Analysis of herderite, Topsham, Maine; analyst Penfield (1886).

Of the monoclinic minerals, herderite shows the least close relation to the orthorhombic minerals. It is probable that herderite is related to the pyrobelonite-end of the adelite group in the following manner.

	<i>Herderite</i>		<i>Pyrobelonite</i>
a_0	9.80	b_0	9.45
b_0	7.68	a_0	7.84
c_0	4.80	c_0	6.09

These are directly comparable since β of herderite is very nearly a right angle ($90^\circ 06'$). The correspondence between the first two terms is reasonably good, but differs considerably in the values for c_0 . This may be due to the differences in size between Mn , Pb ions in the cation positions of pyrobelonite and the Ca and Be ions in the cation positions of herderite.

Herderite also represents a series through the interchange of F and OH . Two names have been given to members of this series, hydroherderite $CaBePO_4(OH, F)$, containing a large percentage of H_2O , and herderite $CaBePO_4(F, OH)$, containing a small percentage of F .

A summary of the significant physical and chemical properties of the monoclinic minerals is given in Table 4.

C. Triclinic Section. There are only two minerals included in this section, amblygonite and tarbuttite. They are not directly comparable but are related to members of other crystallographic sections, as will be shown later.

Amblygonite. The x -ray study was made on a small cleavage fragment of amblygonite from Hebron, Maine. The edge between two cleavages which proved to be $a(100)$ and $c(001)$ was set parallel to the axis of rotation, and rotation and Weissenberg photographs were taken about this axis.

The crystal fragment used was polysynthetically twinned ($\bar{1}01$). The interpretation of photographs of such a twin is somewhat more involved than that of a single individual. In this case, the reciprocal lattice projections of the photographs showed two interpenetrating lattices simply related to each other. Values for the translation periods of the axes on the plane of the projections were calculated for each individual, which therefore increased the accuracy of the resulting calculation.

The measurements and calculations of these photographs give the following lattice constants:

$$\begin{array}{ll} a_0 = 4.92 & a_0 : b_0 : c_0 = 0.698 : 1 : 0.699 \\ b_0 = 7.05 & a : b : c = 0.7334 : 1 : 0.7633 \\ c_0 = 4.93 & \alpha = 107^\circ 22', \beta = 97^\circ 27', \gamma = 109^\circ 50' \\ & \alpha = 108^\circ 51', \beta = 97^\circ 48', \gamma = 106^\circ 27' \text{ (morphology)} \end{array}$$

Space group $C_{2v}^1 - P\bar{1}$.

The geometrical elements and the lattice constants determined by x -ray methods are not in close agreement. The morphological elements were made on large coarse crystals, probably with a contact goniometer. The measurements and calculations therefore must be only approximate.

The writer believes that the calculations of the elements as given above, derived from the x -ray study, are an added refinement to the original work and therefore proposes that these new elements be adopted.

Amblygonite is apparently related to herderite and therefore the pyrobelonite end of the adelite group. The relationship is complex but may be compared through the following reciprocal lattice projection elements:

Amblygonite

$$a^* = 0.336$$

$$b^* = 0.257$$

$$c^* = 0.322$$

Herderite

$$a^* = 0.157$$

$$b^* = 0.201$$

$$c^* = 0.320$$

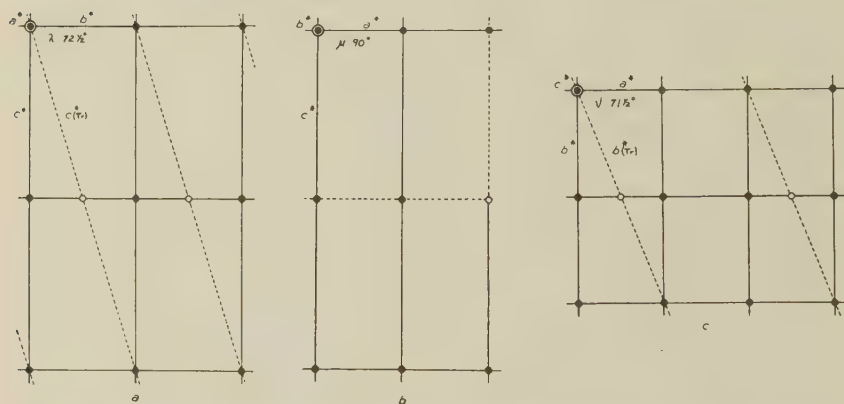


FIG. 4. Reciprocal lattice projections showing the relation of amblygonite to herderite. Solid lines represent the reciprocal cell of herderite, the dotted lines that of amblygonite. Figure 4a is projected on the c^*-b^* plane; figure 4b on the a^*-c^* plane; figure 4c on the a^*-b^* plane.

Figures 4 *a*, *b*, *c* indicate approximately the axial relationships. It will be noted that μ is assumed to be 90° whereas the actual value is $82^\circ 33'$. There is also poor agreement between the two b^* values.

The unit cell formula is $2[(\text{Li}, \text{Na})\text{AlPO}_4(\text{F}, \text{OH})]$ with $\text{F}:\text{OH} = 1:1$ derived from the following table:

	Analysis		Proportions			No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic		Actual	Theory
Al_2O_3	33.90	34.25	0.336	Al 0.672		1.85	2
Li_2O	9.24	9.34	0.312	Li 0.624		1.72	2
Na_2O	0.66	0.66	0.011	Na 0.022		0.61	
P_2O_5	47.44	47.90	0.337	P 0.674		1.86	2
H_2O	5.05	5.11	0.284	H 0.568		1.57	2
F	5.45	5.51	0.289	F 0.287		0.79	
				O 3.039		8.31	10
	101.74	102.77					
Less O	2.73	2.77					
	99.91	100.00					

Specific gravity: measured 3.032; calculated 3.18.

Analysis of amblygonite from Hebron, Maine; analyst Penfield (1879).

Amblygonite Series. Amblygonite is a name applied to a series covering a wide range of chemical variations. These variations are sufficiently systematic to enable one to form a series of very definite compounds, all of which have similar structures as shown by identical powder photographs.

In this series there is a double exchange of cations and elements of the hydroxyl radical. The general formula $(Li, Na)AlPO_4(F, OH)$ expresses this interchange wherein *Li* and *Na*, *F* and *OH* replace each other statistically. From fifteen analyses of amblygonite in Doelter (1918), three from Quensel (1937) and one from Schaller (1912), the molecular ratios of *Li* and *Na* vary from 100:1 to 1:1; the *F* and *OH* vary from 25:1 to 1:8.

Three names have been given by various writers to certain of the intermediate members of the series: amblygonite, containing a low percentage of Na_2O and H_2O ; montebrasite, containing a low percentage of Na_2O but a large percentage of H_2O ; fremontite, containing a high percentage of Na_2O and approximately equal amounts of *F* and H_2O .

Quensel (1937) proposes to limit amblygonite to a compound with *F* content varying from 8-13%, with H_2O less than 3% and a specific gravity of 3.06; montebrasite to be used for a mineral with *F* less than 8%, with water more than 3% and the specific gravity less than 3.06. The writer is in accord with this division since it represents a well-defined partition in the series and also corresponds to the original separation proposed by Descloizeaux (1872). Therefore the three minerals may be designated by the following names and formulae:

amblygonite (Li, Na) $AlPO_4$ (F, OH)
 montebrasite (Li, Na) $AlPO_4$ (OH, F)
 fremontite (Na, Li) $AlPO_4$ (F=OH)

Tarbuttite. The reorientation, lattice constants and space group were previously published by the writer (1938) and are repeated below:

$a_0 = 8.097$ $a_0:b_0:c_0 = 0.6271:1:0.5957$
 $b_0 = 12.91$ $a:b:c = 0.6296:1:0.5971$
 $c_0 = 7.688$ $\alpha = 89^\circ 34\frac{1}{2}'$, $\beta = 91^\circ 37\frac{1}{2}'$, $\gamma = 107^\circ 47'$
 $\alpha = 89^\circ 37\frac{1}{2}'$, $\beta = 91^\circ 28\frac{1}{2}'$, $\gamma = 107^\circ 41'$ (morphology)

Space group $C_{1i} - P\bar{1}$.

Tarbuttite appears to be related to the libethenite group. A reciprocal lattice projection of the zero-layer line of average values for the libethenite group indicates the following relationship:

Tarbuttite	Libethenite Group
$a^* = .200$	$a^* = .190$
$b^* = .125$	$\frac{1}{2}[\frac{1}{2}01]^* = .130$
$c^* = .200$	$b^* = .181$

72°

The angles λ , μ are approximately 90° so that the axial directions a and c of tarbuttite may be assumed to nearly coincide with the axial directions a and b of the libethenite group.

The unit cell formula is $8[\text{Zn}_2\text{PO}_4(\text{OH})]$ derived from the following table:

	Analysis		Proportions		No. of atoms per unit cell	
	Reported	Calculated to 100%	Molecular	Atomic	Actual	Theory
ZnO	66.6	66.9	0.822	Zn 0.822	15.81	16
P ₂ O ₅	29.2	29.3	0.205	P 0.410	7.89	8
H ₂ O	3.8	3.8	0.212	H 0.424	8.14	8
				O 2.059	39.50	40
	99.6	100.0				

Specific gravity: measured 4.15; calculated 4.37.

Analysis of tarbuttite, Broken Hill mines, H. W. Rhodesia; analyst L. J. Spencer (1908).

A summary of the chemical and physical properties of amblygonite and tarbuttite is given in Table 7.

TABLE 7. SUMMARY OF THE CHEMICAL AND PHYSICAL PROPERTIES OF THE TRICLINIC MINERALS

Mineral	Amblygonite	Tarbuttite
Comp.	(Li, Na) $\text{AlPO}_4(\text{F, OH})$	$\text{Zn}_2\text{PO}_4(\text{OH})$
a_0	4.92	8.097
b_0	7.05	12.91
c_0	4.93	7.688
$a_0:b_0:c_0$	0.698:1:0.699	0.6271:1:0.5957
α	$107^\circ 22'$	$89^\circ 34\frac{1}{2}'$
β	$97^\circ 27'$	$91^\circ 37\frac{1}{2}'$
γ	$109^\circ 50'$	$107^\circ 47'$
V_0	151	765
No. of Mol.	2	8
Space Group	C_2^1-PI	C_2^1-PI
H	6	3.7
D	3.01-3.09	4.15
Opt. Orient.		ϕ ρ
X	1.603	7° 58° 1.660
Y	1.613	159 25 1.705
Z	1.626	-86 80 1.713
Sign	Positive	Negative

III. MINERALS PREVIOUSLY CLASSIFIED WITH MEMBERS OF THIS TYPE

The writer has not examined the following minerals by x -ray methods, but from the data available he tentatively places them in their proper relation to minerals of this or other types.

Cornetite. A mineral described by Groth and Mieleitner (1921) from Katanga, Belgian Congo, is said to be isomorphous with libethenite with a formula $(Cu,Co)CuPO_4(OH)$. Schoep (1921) showed that the *Co* was due to admixed heterogenite. Carefully selected material was analyzed by Hutchinson and MacGregor (1921), leading to the composition $13 CuO \cdot 2P_2O_5 \cdot 7H_2O$. This mineral does not conform to the type formula, is therefore not isomorphous with libethenite and cannot be considered a mineral of the chemical type.

Araeoxen. An analysis by Bergemann (1857) gives the weight percentage of V_2O_5 and As_2O_5 as essentially equal. The formula derived from this analysis is $ZnPb(V,As)O_4(OH)$. Analyses of descloizite give percentages of As_2O_5 varying from 0.20–4.78 per cent. Araeoxen may, therefore, be considered as an arsenian variety of the descloizite series.

Brackebuschite. A comparison of the analyses by Doering (1880) with that of pyrobelonite indicates that brackebuschite $(Pb,Mn)_2VO_4(OH)$ with $Pb:Mn=2:1$ and pyrobelonite $(Mn,Pb)_2VO_4(OH)$ with $Mn:Pb=3:2$ form a series.

Spodiosite. Tiborg (1885), Sjögren (1885), and Nordenskjöld (1893) give various formulae for this mineral. It is likely that spodiosite is related to wagnerite with *Mg* replaced by *Ca*, although no new work has been done to verify this conclusion.

Calciovolborthite (tangeite). No adequate material was available for *x*-ray determination. From the analysis by Nenadkewitsch and Wolkow (1926) the composition is $2CaO \cdot 2CuO \cdot V_2O_5 \cdot H_2O$ or $2CaCuVO_4(OH)$. This mineral belongs in the adelite group and is closely related to higginsite $CaCuAsO_4(OH)$.

Pseudotriplite. A comparison of the analysis by Delffs (1894) with that of triplite indicates that pseudotriplite is an iron-rich triplite and a member of that series.

Allauaudite. The analysis by Damour (1848) indicates that allauaudite is a member of the triphylite series and, therefore, does not conform to the type.

Sarcopside. The analysis by Holden (1920) indicates that sarcopside $(Fe,Mn,Ca)_2PO_4(F)$ is closely related to triplite $(Fe,Mn)_2PO_4(F)$ differing only in essential amounts of *Ca*. It may, therefore, be considered as a member of the triplite series.

Xanthoarsenite. An analysis by Igelström (1884) indicates this mineral contains *Sb*, but his analysis groups together the percentages of As_2O_5 and Sb_2O_5 . Analyses of sarkinite show per cents of Sb_2O_5 up to 1.37%. Since no definite amount of Sb_2O_5 is given, xanthoarsenite $Mn_2(As,Sb)O_4(OH)$ must be considered a doubtful species and, if retained, should be classed as an antimonian variety of sarkinite.

Melanchlor. This alteration product of triplite, described by Fuchs (1839), is essentially an hydrous phosphate of ferric iron with no definite formula.

Morinite and Soumansite. These are alteration products of amblygonite forming hydrous compounds of complex composition but do not belong to the type.

IV. ACKNOWLEDGMENTS

The writer is indebted particularly to Dr. Harry Berman for his unflagging interest and helpful criticism during the progress of this research, and to Professor Charles Palache at whose suggestion and under whose tutelage this work has been carried out. To these men the writer wishes to extend his gratitude for the inspiration that has made this paper possible.

V. REFERENCES

- AMINOFF, A. (1933): *Kungl. Sven. Vetenskapsakad. Hand.*, ser. 3, **11**, #4, 24.
 BANNISTER, F. A. (1933): *Min. Mag.*, **23**, 376.
 BERGEMANN, C. W. (1857): *N. Jahr. Min.*, 397.
 BERMAN, H. (1937): *Am. Mineral.*, **22**, 342.
 DAMOUR, A. (1848): *Anal. d. Min.*, **13**, 341.
 DANA, E. S. (1892): *System of Mineralogy*, New York.
 DELFFS, F. W. H. (1894): *Lehrb. Min.*, **4**, 494.
 DESCLOIZEAUX, A. (1872): *Annal. Chem. Phys.*, **27**, 385.
 DOELTER, C. (1918): *Handb. der Min. Chem.*, **3**, #1, 479, 649.
 DOERING, A. (1880): *Zeits. D. Geol. Ges.*, **32**, 708.
 DONNAY, J. D. H. (in Peacock, 1937): *Am. Mineral.*, **22**, 621.
 DÜRRFELD, V. (1909): *Zeits. Kryst.*, **46**, 563.
 FIELD, F. (1875): *Min. Chem.*, 400.
 FUCHS, C. W. (1839): *Jour. Prakt. Chem.*, **17**, 171.
 GOLDSCHMIDT, V. (1897): *Kryst. Winkeltabellen*, Berlin.
 GROTH, P. H., AND MIELEITNER (1921): *Min. Tab.*, 67.
 GRUNER, J. W., and McCONNELL, D. (1938): *Zeits. Kryst.*, **97**, 208.
 HAMBERG, A. (1888): *Zeits. Kryst.*, **17**, 431.
 HAWES, G. W. (1876): *Am. Jour. Sci.*, **11**, 476.
 HERITSCH, H. (1937): *Zeits. Kryst.*, **98**, 351.
 HILLEBRAND, W. F. (1886): *Zeits. Kryst.*, **11**, 286.
 HINTZE, C. (1931): *Handb. der Min.*, **1**, 4A, 708.
 HOLDEN, E. F. (1920): *Am. Mineral.*, **5**, 99.
 HURBUT, C. S. (1936): *Am. Mineral.*, **21**, 656.
 HUTCHINSON, A., AND MACGREGOR, A. M. (1921): *Min. Mag.*, **19**, 225.
 IGELSTROM, L. J. (1884): *Bull. Soc. Min. Franc.*, **7**, 237.
 KOKKOROS, P. (1937): in *Zeits. Kryst.*, **99**, 38.
 MACHATSCHKI, F. (1930): *Zeits. Kryst.*, **73**, 123.
 MAUZELIUS, R. (1895): in *Zeits. Kryst.*, **28**, 509.
 ——— (1919): *Geol. Fören. Förh.*, **41**, 433.
 MELCZER, C. (1904): *Zeits. Kryst.*, **39**, 288.
 MILLER, W. H. (1879): in *Zeits. Kryst.*, **3**, 471.

- NENADKEWITSCH, K., AND WOLKOW, P. (1926): *Comp. Rendu Acad. de-Sc. l'U.S.S.R.*, 43.
- NORDENSKJÖLD, G. (1893): *Geol. Fören. Förh.*, **15**, 460.
- PALACHE, C., AND SHANNON, E. V. (1920): *Am. Mineral.*, **5**, 150.
- PEACOCK, M. A. (1937): *Am. Mineral.*, **22**, 588.
- PENFIELD, S. L. (1878): *Am. Jour. Sci.*, **16**, 42.
- (1879): *Am. Jour. Sci.*, **18**, 295.
- (1886): *Am. Jour. Sci.*, **32**, 107.
- PUFAHL, O. (1920): *Central. Min.*, 295.
- QUENSEL, P. (1937): *Geol. Fören. Förh.*, **90**, 455.
- RAMMELSBURG, C. F. (1880): *Mon. Ber. Berliner Acad. Wiss.*, 652.
- RICHMOND, W. E. (1938): *Am. Mineral.*, **23**, 881.
- RICHMOND, W. E., AND WOLFE, C. W. (1938): *Am. Mineral.*, **23**, 799.
- (1939): In preparation.
- ROSICKÝ, V. (1908): in *Zeits. Kryst.*, **48**, 656.
- ST. NARAY-SZABO, TAYLOR, W. H., AND JACKSON, W. W. (1928): *Proc. Roy. Soc.*, **A**, **119**, 132.
- SCCACHI, A., AND E. (1883): *Atti R. Ac.*, **1**.
- SCHALLER, W. T. (1912): *U.S.G.S., Bull.* **509**.
- SCHOEP, A. (1921): *Min. Mag.*, **19**, 301.
- SJÖGREN, A. (1885): *Geol. Fören. Förh.*, **7**, 666.
- SJÖGREN, H. (1894): *Bull. Geol. Inst. Upsala*, **1**, 1.
- SPENCER, L. J. (1908): *Min. Mag.*, **15**, 22.
- STAPLES, L. W. (1935): *Am. Mineral.*, **20**, 112.
- STILLWELL, C. W. (1938): *Crystal Chemistry*, New York.
- STRUNZ, H. (1936): *Zeits. Kryst.*, **93**, 146.
- (1937): *Zentral. Min.*, Abt. **A**, #2, 59.
- TAYLOR, W. H. (1928): *Zeits. Kryst.*, **68**, 503.
- (1929): *Zeits. Kryst.*, **71**, 205.
- TIBORG, H. V. (1885): *Geol. Fören. Förh.*, **1**, 84.
- UNGEMACH, H. (1921): *Bull. Soc. Min. Franc.*, **44**, 122.
- YATSEVITCH, G. M. (1935): *Am. Mineral.*, **20**, 426.
- ZAMBONINI, F. (1910): *Min. Vesuv.*, 2ed., 200, Naples.

AGE OF THE URANINITE FROM THE McLEAR
PEGMATITE NEAR RICHVILLE STATION,
ST. LAWRENCE COUNTY, NEW YORK

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The McLearn pegmatite, which was discovered in 1907, is located in the Gouverneur Quadrangle, 3.8 miles north $47^{\circ}45'$ east from Richville Station, St. Lawrence County, New York, or at latitude $44^{\circ}27'32.4''$ north and longitude $75^{\circ}18'39.6''$ west, locality 9, Fig. 1.

The mine has been in active operation for a large part of the time since the initial development work, however, during the past two years the property has been temporarily closed down. The pegmatite occurs in highly metamorphosed limestone of the Grenville series¹ and is parallel to the strike of the beds. In 1929 the writer² made a detailed study of the pegmatite but did not at that time observe the occurrence of uraninite or any of the decomposition products. In the autumn of 1936 the writer visited the locality and collected a number of specimens, on the dump from shaft number 2, containing small black mineral grains. These were not examined in detail until the spring of 1938 when cubes of uraninite were identified. On subsequent visits to the property, approximately 10 grams of uraninite have been obtained.

MODE OF OCCURRENCE AND CRYSTAL HABIT OF THE URANINITE

The chief mode of occurrence is that of small cubes, Fig. 2, which measure up to 5 mm. along an edge. The cubes are rarely modified by the rhombic dodecahedron and very rarely by the octahedron. A number of penetration twins, Fig. 3, were observed. The crystals are most commonly imbedded in *white* quartz which is quite unusual, for all previous occurrences observed by the writer at other localities the crystals were associated with smoky quartz. The uraninite is coated with a white material which gives the crystals a rough appearance. The crystals are usually very fresh and unaltered when they occur in quartz, from which they are frequently obtained without much fracturing of the uraninite due to the fact that the quartz is finely fractured throughout the pegmatite. Occasionally the uraninite in the quartz is altered to a black mass which is readily reduced to a powder between the fingers. The feldspar, which is usually a mixture of granular microcline perthite and albite, also occasionally contains grains of uraninite which do not produce any noticeable darkening of the feldspar in contrast to the feldspar of the Canadian pegmatities which is conspicuously colored a reddish brown in

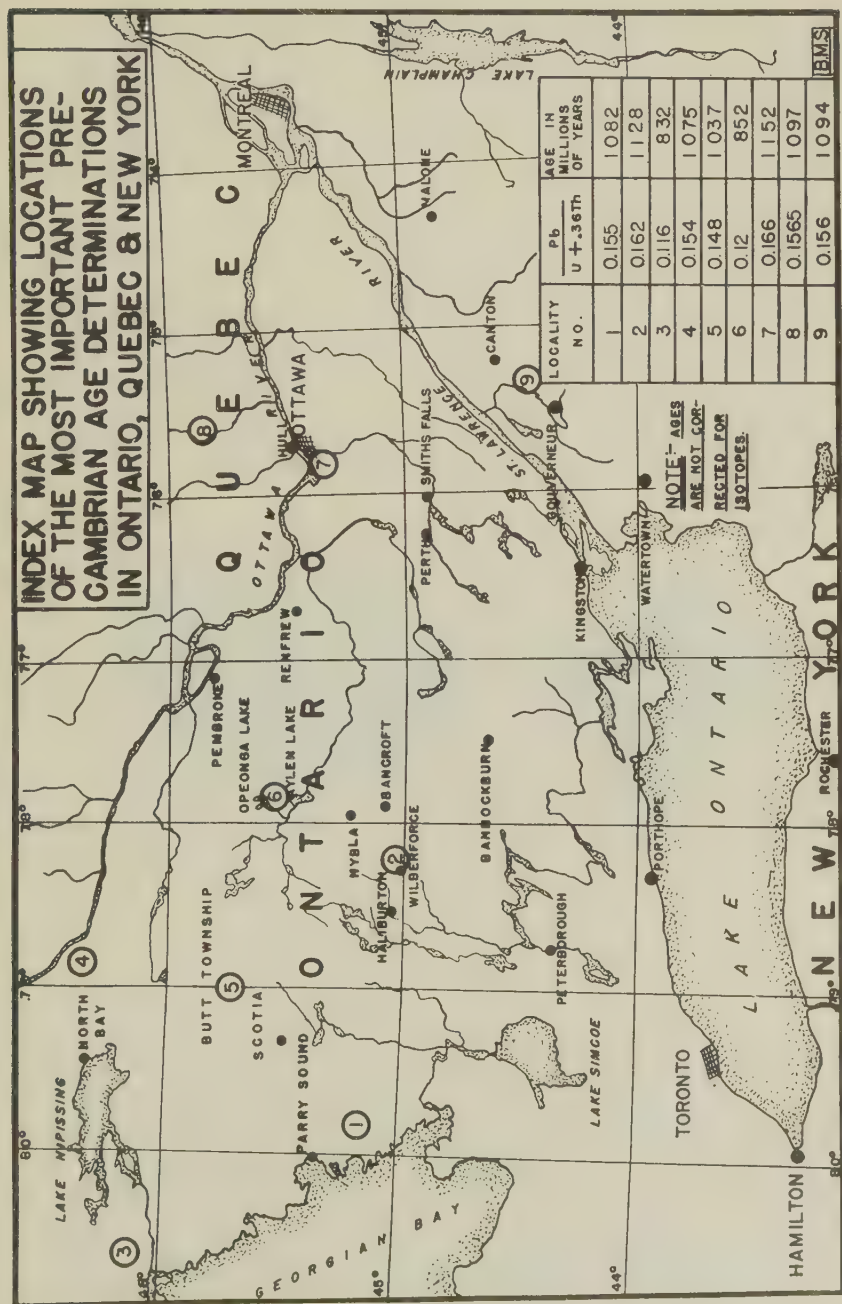


Fig. 1. Map showing locations of occurrences of radioactive minerals in Ontario, Quebec, and New York listed in Table 1.

the vicinity of the uraninite.³ Irregular grains of uraninite without crystal faces occur imbedded in greenish tremolite crystals which are associated with the quartz and sphene. Both tremolite and sphene are often abundant. The usual orange and yellow alteration products do not occur with the uraninite associated with the quartz, and very rarely with that associated with the tremolite.

One of the common minerals of the pegmatite is diopside which is sometimes altered, especially when it occurs in larger crystals. Associated with the altered diopside crystals and grains, as well as with calcite, one sometimes finds a black radioactive material which is usually powdery and originally may have been uraninite. The material is sometimes rather firm and resembles the thucholite from the Ontario pegmatites. Owing to the very small quantity of the material available a detailed examination has not yet been undertaken. It is hoped that further search may reveal an additional quantity for continued investigation.

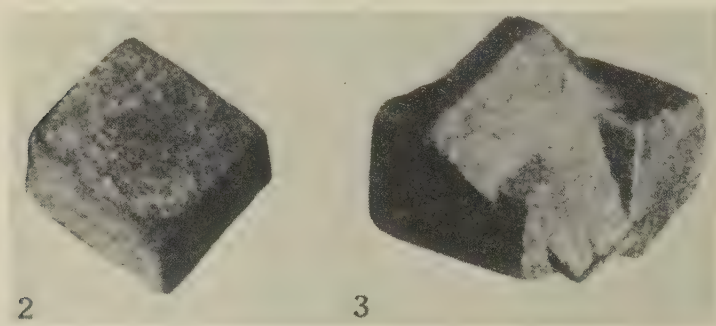


FIG. 2. Uraninite cube from the McLearn pegmatite, St. Lawrence County, New York. $X=10$.

FIG. 3. Twinned uraninite cubes from the McLearn pegmatite, St. Lawrence County, New York. $X=9$.

CHEMICAL COMPOSITION OF THE URANINITE

A number of the freshest looking crystals were tested on photographic plates for their radioactivity, which produced strong radiograms in 36 hours. One of the good crystals was selected for analysis and the rough coating removed by means of fine carborundum cloth, after which it weighed 192 milligrams and had a specific gravity of 9.03. The crystal was sent to Dr. Friedrich Hecht of Vienna for a microchemical analysis. The work was done by Th. I. Koss-Rosenqvist of Oslo under Dr. Hecht's directions. His determinations are as follows:

Insoluble residue after evaporating with HNO_3	0.45%
(of which SiO_2 is).....	(0.37)
PbO	11.57
(Pb).....	(10.74)
Al_2O_3	0.03
Fe_2O_3	0.92
Rare earths.....	4.44
CaO	2.50
MgO	1.16
ThO_2	5.20
(Th).....	(4.57)
UO_2	75.89
(U).....	(66.90)
P_2O_5	trace
H_2O (-).....	0.07
H_2O (+).....	not determined
S.....	0.20
"Loss by ignition" increase in weight.	

 102.80

The lead-uranium-thorium ratio $\left(\frac{\text{Pb}}{\text{U} + 0.36 \text{ Th}} \right)$ is 0.156.

Although all of the uranium is reported as UO_2 , Dr. Hecht states⁴ that most of the uranium "seems to be present in the form of UO_2 because increase in weight has been found instead of loss by ignition." He further states that he would not say that the "*whole* uranium would be UO_2 ."

As very fine-grained pyrite is not uncommon in association with the pegmatite minerals it is not unlikely that the small amount of sulphur present was combined with a corresponding part of the iron as pyrite rather than with ordinary lead in galena. The latter is of extremely rare occurrence in the pegmatite.

AGE OF THE URANINITE

As one cannot determine from the microchemical analyses the amount of ordinary lead that may be present, if any, the entire amount of lead present must be assumed, for purposes of tentative age determination, to be uranium lead. As obtained from the analysis the lead-uranium-thorium ratio $\text{Pb}/(\text{U} + 0.36 \text{ Th})$ is 0.156, which according to Holmes⁵ is of Laurentian age, or about the middle of the pre-Cambrian.

The occurrence of uraninite in the McLearn pegmatite is believed to be the first to be recorded in the Grenville formation of New York State and is of interest in correlating the ages of the formations of St. Lawrence County with those of Ontario. A tabulation of the ratios determined from the best material investigated, chiefly uraninite, is given in Table 1.

TABLE 1. TABULATION OF SOME LEAD-URANIUM-THORIUM RATIOS FOR AREAS IN ONTARIO, QUEBEC AND NEW YORK

Locality Numbers refer to locations on map, Fig. 1	Mineral analyzed	"Lead- uranium" ratios of the analyses	$t = \text{age in millions of years} = 15140 \log \left(1 + \frac{1.115 \text{ Pb}}{\text{U} + .36 \text{ Th}} \right)$
(1) Conger Township, Parry Sound Dist., Ont. (McQuire-Robinson claim).	Uraninite (<i>Ellsworth</i>) ^a	0.155	1082
(2) Wilberforce, Cardiff Township, Haliburton County, Ontario, Lots 4 & 5, Con. 21.	Uraninite (<i>Ellsworth</i> , 2 analyses) ^b	0.157 0.172	1097 1195
	(<i>Todd</i>) ^c	0.151	1056
	(<i>Wells</i>) ^d	0.162	1125
	(<i>Hecht & Reich-Rokrig</i> , 2 analyses) ^e	0.173 0.159	1204 1110
	(<i>Aller & Kipp</i> 2 analyses) ^f	0.160 0.157	1116 1100
	(<i>Hecht</i>) ^g	0.163	1137
	(<i>Kroupa</i>) ^g	0.164	1142
		Av. 0.162	Av. 1128
(3) Henvey Township, Parry Sound Dist., Ont. Bessner Mine, Lot 5, Con. B.	Uraninite (<i>Ellsworth</i>) ^h	0.116	832
(4) Matawan Township, Nipissing Dist., Ont. O'Brien Mine, Lot 29, Con. 3.	Euxenite-poly- crase (<i>Ellsworth</i>) ⁱ	0.154	1075
(5) Butt Township, Nipissing Dist., Ont. Wm. Elliott Mine, Lot 13, Con. 7.	Uraninite (<i>Ellsworth</i> 2 analyses) ^j	0.148	1037
		0.148	1037
(6) Dickens Township, Nipissing Dist., Ont. Armstrong Claim, Lot 9, Con. 13.	Monazite (<i>Ellsworth</i>) ^k	0.12	852
(7) March Township, Carlton County, Ont. Lot 6, Con. 2.	Uraninite (<i>Ellsworth</i>) ^l	0.166	1152

TABLE 1. TABULATION OF SOME LEAD-URANIUM-THORIUM RATIOS FOR AREAS IN ONTARIO, QUEBEC AND NEW YORK—(Continued)

Locality Numbers refer to locations on map, Fig. 1	Mineral analyzed	"Lead- uranium" ratios of the analyses	t = age in millions of years = $15140 \log$ $\left(1 + \frac{1.115 \text{ Pb}}{\text{U} + .36 \text{ Th}}\right)$
(8) Villeneuve Township, Papineau County, Que. Lot 31, Range 1, Villeneuve Mine.	Uraninite (Hillebrand) ^m (Ellsworth) ⁿ	0.156	1094
		0.157	1100
(9) St. Lawrence County, New York, 3.8 miles N 47°45' E from Richville Station, Mc- Lear pegmatite, No. 2 Shaft.	Uraninite (Koss-Rosenqvist)	0.156	1094

^a Ellsworth, H. V., Radium-bearing pegmatites of Ontario: Summary Report, 1911, Part D, p. 60, *Geological Survey, Canada Department of Mines, Ottawa, Ontario*.

^b Ellsworth, H. V., Recent discoveries of radioactive minerals in Ontario: Summary Report, 1923, Part C1, p. 20, *Geological Survey, Canada Department of Mines, Ottawa, Ontario*.

Ellsworth, H. V., Rare-element minerals of Canada, 268-269 (1932), *Economic Geology Series No. 11, Geological Survey, Canada Department of Mines, Ottawa, Ontario*.

^c Walker, T. L., Uraninite from Cardiff Township, Ontario: *University of Toronto Studies, Geol. Series* 17, 43, 1924.

^d Wells, R. C., Analysis appears in Kirsh, Gerhard, and Lane, Alfred C., Radioactive disintegration applied to the measurement of geologic time illustrated by application to the Wilberforce Uraninite: *Proc. Am. Acad. Arts and Sci.*, 66, 365 (1931).

^e Report of the Committee on the Measurement of Geologic Time, p. 21, April 22, 1933, *National Research Council, Washington, D. C.*

^f Alter, C. M., and Kipp, Egbert M., The variation of the lead-uranium-thorium ratio of a single crystal from Wilberforce, Ontario, Uraninite: *Am. Jour. Sci.*, 32, 120-128 (1936).

^g Report of the Committee on the Measurement of Geologic Time, p. 56, May 1937, *National Research Council, Washington, D. C.*

^h Ellsworth, H. V., Uraninite from Henvey Township, Parry Sound District, Ontario: *Am. Mineral.*, 16, 576-579 (1931).

ⁱ Ellsworth, H. V., Euxenite-polycrase from Mattawan Township, Nipissing District, Ontario: *Am. Mineral.*, 11, 329-331 (1926).

^j Ellsworth, H. V., Rare-element minerals of Canada, 268-269 (1932): *Economic Geology Series, No. 11, Geological Survey Canada*.

^k Ellsworth, H. V., Monazite colored by carbon from Dickens Township, Nipissing District, Ontario: *Am. Mineral.*, 17, 19-28 (1932).

^l Ellsworth, H. V., Rare-element minerals of Canada, 268-269 (1932): *Economic Geology Series, No. 11, Geological Survey Canada*.

^m Hillebrand, W. F., New analyses of uraninite: *Am. Jour. Sci.*, 42, 390-393 (1891).

ⁿ Ellsworth, H. V., Rare-element minerals of Canada, 272 (1932): *Economic Geology Series, No. 11, Geological Survey Canada*.

Many analyses of radioactive minerals of the Grenville area in Ontario were consulted, but unless the material used was believed by the investigators to be essentially free from alteration, they were not included. Some of the analyses of the middle and central parts of crystals which were slightly altered at the surface were included when the results of the analyses were in good agreement. Most of the analyses of uranium-bearing minerals which have a very low percentage of uranium do not give consistent ratios; hence, they were in general not included.

With the exception of the uraninite from the Bessner Mine, locality 3, and the monazite from the Armstrong claim, locality 6, it is of interest to note the close agreement in age between uranium-bearing minerals as widely distributed as shown on the map, Fig. 1. The age of the first two is distinctly younger than the others and they are probably Huronian rather than Laurentian.

The computed ages for the uranium-bearing minerals shown in Table 1, except numbers 3 and 6, show a rather remarkable agreement when one considers the many possible variables which may enter into the final figures. While a large fraction of the variations may be assigned to the probable loss of constituents of the minerals by alteration, nevertheless, there may be a distinct difference in the actual periods when the pegmatite deposits originated, for one would hardly expect the intrusion and crystallization of the pegmatite magmas to be simultaneous over such a large area. Expressed in per cent above and below the average we have 8.75 and 6.3 per cents, respectively. The age of the uraninite from the McLearn pegmatite differs from the average by being 1.2 per cent lower.

Nier's⁶ determination of the age of the Wilberforce uraninite on the basis of the relative abundance of lead isotopes gives the age from RaG/U^{238} to be 1077×10^6 years and from AcD/RaG to be 1035×10^6 years. These ages differ between themselves and are somewhat lower than the average age (1128×10^6) determined by use of the logarithmic formula.

ACKNOWLEDGMENTS

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REFERENCES

1. CUSHING, H. P., AND NEWLAND, D. H., Geology of the Gouverneur Quadrangle: *N. Y. State Mus., Bull.* **259**, 18-50 (1925).
2. SHAUB, B. M., A unique feldspar deposit near DeKalb Junction, New York: *Ec. Geology*, **24**, 68-89 (1929).

3. ELLSWORTH, H. V., Radium-bearing pegmatites of Ontario; Summary Report, **1921**, Part D, p. 57, *Geological Survey, Canada Department of Mines, Ottawa, Ontario*.
4. Personal communication.
5. HOLMES, ARTHUR, *The Age of the Earth*, p. 204, Thomas Nelson & Sons, Ltd., London & New York (1937).
6. NIER, ALFRED O., The isotopic constitution of radiogenic leads and the measurement of geological time. II: *Physical Review*, **55**, 159 (1939).

WILLEMITE MORPHOLOGY AND PARAGENESIS AT BALMAT, NEW YORK

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The occurrence of supergene willemite (Zn_2SiO_4) has been mentioned briefly in a paper on the St. Joseph Lead Company Mine at Balmat, St. Lawrence County, New York, by John S. Brown (1936). No other description of the willemite of this locality has appeared, though it is an unusual and interesting occurrence yielding splendid material for study. The writer of this paper wishes to express his appreciation to Dr. Brown for his cooperation at the time of a visit to the mine and since, through the gift of specimens, and a critical reading of the manuscript.

The willemite occurs in a lens extending to some depth below a strongly oxidized portion of the deposit. The upper levels contain considerable secondary sulphides, and oxide minerals. The willemite zone below this is marked by the dominance of a talc-chlorite replacement of the rock, and willemite, with some hematite. The willemite is present in some quantity and is potentially a considerable deposit, but no use of this ore is being made at the present time. The associated minerals include (in addition to the ubiquitous talc-chlorite) tremolite, hematite, galena, garnet, barite, and, though not in the same specimens, ilvaite.

There is general agreement among those who have studied the region (Smyth, 1894; Buddington, 1917; Brown, 1936) that most of the chlorite is supergene and that it is distinctive, and recognizable. The willemite and the ilvaite occur as euhedral crystals embedded in this chlorite, and appear to have been formed by rock replacement. A close study of the specimens shows several stages of mineral formation which are of great interest. Brown (1936) has described the appearance of the willemite-chlorite growth in thin-section, but gave no morphological data.

Two types of willemite crystals were observed in the specimens studied. The dominant and abundant crystals are embedded in the chlorite. They are small, about 1 mm. thick and 2 to $2\frac{1}{2}$ mm. in diameter. The habit is tabular, $c\{0001\}$ is small, $e\{01\bar{1}2\}$ large, and $a\{11\bar{2}0\}$ is the only prism form. They are often ideally developed, with perfect smooth, though dull, faces and sharp edges. The centers are colorless and transparent; toward the edge they tend to become increasingly cloudy with dendritic chlorite and hematite inclusions, which make them gray or red and opaque. Broken crystals have a good cleavage parallel to a . Corners of intergrown crystals were observed to project from c , but no regularity

of orientation which would indicate a twin relationship was found. The crystals are easily removed from the talc-chlorite matrix in which they are embedded, and they leave sharp impressions of their outlines in the compact chlorite.

Not all of the willemite crystals have the small c face shown in Fig. 1; sometimes c is very large and e so small that the crystals look like flat hexagonal plates, as shown in Fig. 2. These also occur in the compact

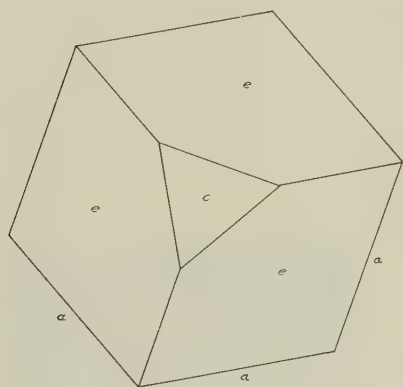


FIG. 1

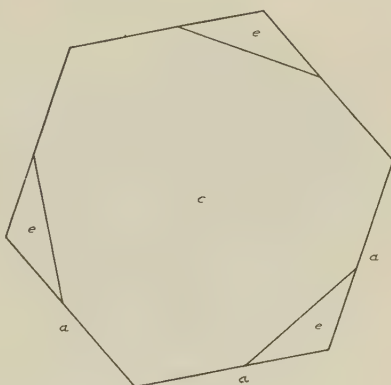
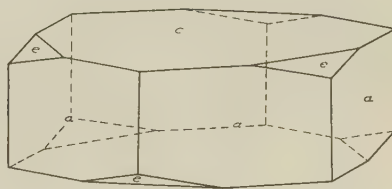
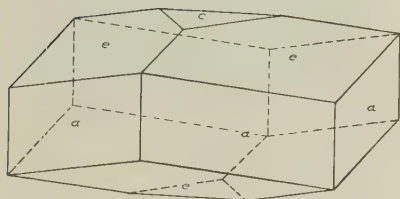


FIG. 2



chlorite and break cleanly from it. There is another type of willemite in this occurrence, however, which is different from the embedded crystals. Although the chlorite is, in general, very fine-grained and compact, a specimen was found containing numerous druses, lined with minute, irregular flaky crystals of chlorite, specular hematite and a limpid willemite. The cavities are very irregular in shape, full of angles and depressions, where the chlorite has coated the simple earlier willemite crystals. The later crystals have no, or very little, attached chlorite, are much smaller in size, rarely attaining even 1 mm. in diameter, and are outstanding for the complexity of the prism forms and their striated bases. Such a pocket is well shown in Fig. 4.

The late willemite crystals are similar in habit to the common crystals, definitely tabular, with c large and strongly striated parallel to its intersections with $e\{01\bar{1}2\}$. The striations mark an intergrowth with that form. Toward the edge, e is frequently cut off by the development of smaller forms, commonly $u\{2\bar{1}13\}$ or $S\{11\bar{2}3\}$, and $r\{10\bar{1}1\}$.

A crystal of this type is shown in Fig. 3. The small size and frequent etching of the crystals made some of the new terminal forms measured

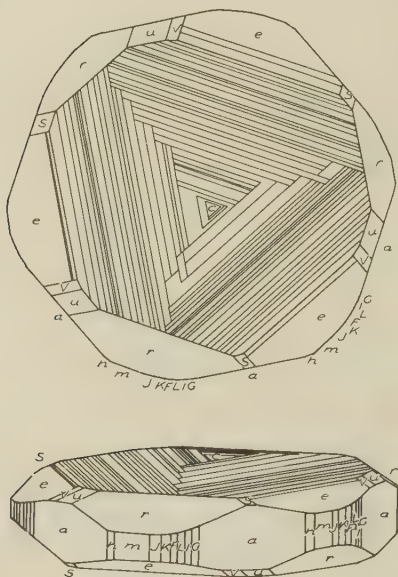


FIG. 3

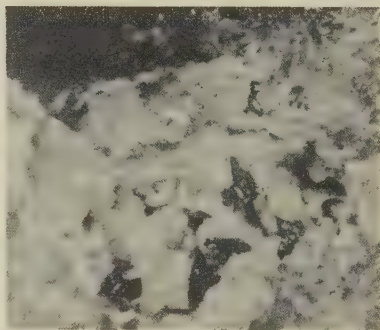


FIG. 4

very doubtful and none are acceptable as new forms. Palache (1928) mentions several new prisms which require confirmation, two of which were frequently found on the 15 crystals measured. The prism zone in the Balmat willemites showed a strongly striated character, and the reflections from the many faces appeared on the goniometer as a continuous train. It would be possible to add many more forms to the list of prisms, as planes could be found in almost any position on the proper half of the sextant, but it was not felt that they would be of any significance. Occasional stronger reflections were found repeatedly in the train, and these have been accepted as prism forms, with simple indices. The table shows the measured and calculated ϕ angles of the new accepted prisms, and lists a and m for comparison regarding the number of times observed.

<i>Observer</i>	<i>Bravais</i>	<i>Meas. Av. ϕ</i>	<i>Obs.</i>	<i>Calc. ϕ</i>	<i>Letter</i>
Common	10 $\bar{1}$ 0	—° ' ,	63	0°00'	<i>a</i>
New	8.5.13.0	+ 7 58	5	+ 7 35	<i>G</i>
Palache?	2130	+10 41	4	+10 53	<i>I</i>
1928					
New	5270	+13 05	3	+13 54	<i>L</i>
New	4150	+20 10	7	+19 06	<i>K</i>
Palache?	7180	+23 50	6	+23 25	<i>J</i>
1928					
Common	1120	—	19	+30 00	<i>m</i>
Common	1230	—	2	—10 53	<i>h</i>

In addition to the cases in which the new forms, and old ones needing confirmation, were specifically measured, they were observed frequently in approximate positions in the train, but so indefinitely located that accurate measurements could not be made. Many other forms were observed and measured but were either irrational in their indices or not duplicated on other crystals, and so were not considered. It was felt that the truest picture of the striated zone of the Balmat willemite could be derived from these few good forms and a recognition of the multiplicity of planes in this zone.

The important conclusion to be derived from these observations is that the tetartohedry is pronounced and shows in the prism zone as well as elsewhere. The crystal in Fig. 3 was selected to show the tetartohedry of the mineral, the nature of the prism forms and their distribution, and the striated character of the base. As may be seen, the prism forms occupy principally one-half of each sextant, and the train-of-reflections in that half is practically continuous. The complimentary half is either all dark, or lightened only by a streak near $h\{12\bar{3}0\}$.

A similar train-of-reflections, usually without significant lighter patches, runs from *c* to each face of *e*. A strongly etched crystal with well-formed triangular pits showed two planes in this train, at $\{01\bar{1}3\}$ and $\{01\bar{1}6\}$, but as they were observed only on etched crystals, they cannot be termed acceptable forms. The tetartohedry of the mineral was not pronounced in these etch pits nor in the striations on *c*, although a few of the etched crystals did give an indication of a break and change in direction of the outer striations.

The form development, however, does show a tetartohedral character, and it is possible to determine the top and bottom of the crystal in this way. Since $V\{1\bar{3}2\bar{5}\}$ was originally described as a right form, it was taken as the criterion for top and bottom whenever it was observed. It occurred with a reasonable frequency on the Balmat crystals and permitted the distinction to be made with confidence. $u\{2\bar{1}1\bar{3}\}$ was more common than $S\{11\bar{2}3\}$ and often larger, the series e - V - u was observed

many times, the signals following each other closely, with what amounted almost to a train-of-reflections, with a gap before the other forms of the zone, r and a .

With all tetartohedral minerals there is great danger of confusion of right and left forms. It seems probable that there has been some in the case of willemite, and a re-study of Franklin willemites might be advisable to clear up this question and to establish criteria upon which distinctions between the forms might be based. The Balmat willemite, interesting as it is, is too poor in forms for certainty, and later work may prove that the striated prism zone should be oriented in the left of the sextant. Until that time it is unwise to change the letter usage as given to make it conform to a tetartohedral treatment, but some confusion has arisen through the use by Palache (1928) of H and h , once as $h\{13\bar{4}4\}$ and later as $H\{13\bar{4}4\}$, with $h\{12\bar{3}0\}$ (Palache, 1935). It would probably be better in the future to assign a new letter to this form.

The Balmat willemite is not fluorescent and appears to be very pure. The only color ever observed in the crystals is from actual inclusions of chlorite, and hematite, and the crystals are opaque and greenish gray or reddish, as would be expected.

A considerable suite of other minerals was observed, more or less intimately associated with the willemite. Of these, the most interesting and unusual is the ilvaite mentioned by Brown (1936). It was not observed by the writer in any of the willemite specimens, but occurs in a darker and more compact chlorite as distinct crystals several mm. long.¹ The matrix in which these lie is darker and, according to Brown, most strongly altered. Sphalerite and pyroxene, the latter in process of alteration, were observed in the same specimens, and galena was seen to coat one of the ilvaite crystals and to form small thread-like veins in the chlorite.

A crystal of ilvaite was measured and the smooth brilliant faces found to be those of the unit prism. The terminations of all the crystals are irregular and dull, the growing ilvaite probably replaced the chlorite very successfully in developing its prism faces, but was less powerful normal to the c -axis and developed only irregular planes. On the goniometer these gave fair signals, none the less, for $r\{101\}$ and $k\{106\}$. No base was found, and only a very narrow a .

Hematite is abundant and occurs as an earthy red material, as compact pseudomorphs after pyrite and wall rock, and as specular crystals. These latter are very small, about the size of the willemite crystals of the vugs, and (in many specimens) occur with them. They are well shown in their typical occurrence in Fig. 4. Some of the specular hematite is

¹ Brown writes "I have it in one willemite-bearing thin section, I think."

found embedded in the chlorite or in the red hematite, but most of the crystals are found in the little druses in the chlorite in which the willemite occurs. They are, in fact, good guides to the willemite, for with their brilliant luster and dark color they are much more easily seen than the clear willemite crystals. The crystals are thin tablets, with a small base and $\mu \cdot \{01\bar{1}5\}$ dominant and strongly striated, $\phi \cdot \{02\bar{2}1\}$, $\delta \cdot \{01\bar{1}2\}$, $\lambda \{22\bar{4}3\}$ and $p \{10\bar{1}1\}$ are also present on most crystals. (Letters of Maurice (1932) used.)

Tremolite and barite are present in the specimens but as residual grains, of irregular outline and largely replaced by the chlorite and willemite. Brown speaks of them both as being seen in thin sections in the process of being altered, and all that were observed in the hand specimens were similarly changed. However, one mineral in apparently fresh crystals, but which may be a residual silicate, was observed. Andradite garnet is described by Brown as being abundant in some of the secondary sphalerite ore, and small clusters of it were found in the vuggy willemite specimen.

The age relationships of this garnet are very difficult to determine, from the small amount of material available. A few .2 mm. dodecahedral crystals were found in a pocket attached to the chlorite, in relationships which would ordinarily suggest a later crystallization, exactly as the hematite and the clear willemite crystals grew. Neither of these minerals was present in the cavity. Elsewhere garnet has replaced early minerals but has been replaced itself by sphalerite and willemite. Regarding this specimen Brown writes,² "As to the garnet, this gave me a great deal of trouble early in my paragenetic study, and I had to cut numerous thin sections to reach a decision, but I think the result was conclusive. Garnet is earlier than, and in some cases, definitely replaced by willemite, by secondary sphalerite, and by primary sphalerite. Therefore, barring the almost impossible assumption of two ages of garnet, it must be prior to all of them. I wonder if the crystals perched on chlorite or willemite cannot be interpreted as residuals left in relief by the (supergene) solution and removal of a matrix of carbonate or barite in which they formerly were embedded? Garnet is strongly stained and to some degree replaced by hematite, which frequently turns the yellow into a brilliant red aggregate."

Mention has already been made of the sphalerite and galena in the chlorite associated with the ilvaite. It is stated by Brown (1936) that "Willemite has nowhere been found microscopically in contact with sulphides, either primary or secondary." A careful study of the drusy willemite specimen revealed a few traces of sulphide, however, in what is

² Letter, dated April 3, 1940.

obviously a secondary relationship. Galena was found in a single case in distinct, though minute crystals, showing the cube with its corners truncated by the octahedron, actually grown upon a willemite crystal. It is shown in Fig. 5, the broad white face being the reflecting surface of the willemite base with small triangular etch pits, and several small groups of galena grown upon it. The crystals are about .6 mm. across, while the willemite crystal, 2.5 mm. across is the largest of the late willemite that was found. A few more galena crystals are attached to the prism planes and another group is visible at the margin between the large willemite and a smaller one.

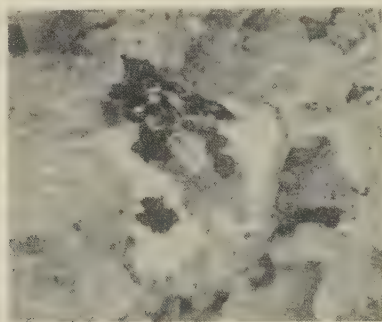


FIG. 5

The last mineral to form is a fibrous, serpentinous material which loosely fills many of the willemite-specularite druses. It is present in very small quantities and is so loosely grown in the pockets that it resembles wisps of smoke making a bluish haze through which one looks at the crystals. It is easily removed, but is often attached firmly enough to the crystals of the other two minerals so that they are drawn out with it. They are then easily freed from the serpentine, however, just as silk fibers or cobwebs might be pulled from a clean surface.

PARAGENESIS

The talcose-chloritic-willemite and chloritic-ilvaite rock is considered to be a replacement of an earlier silicate rock. Brown (1936) says, "The chlorite is an alteration product of diopside and talc, and to some extent of the tremolite, and is believed to have been formed by solutions high in ferrous iron derived from the oxidizing ore bodies. Much of it appears

to be a conversion of talc, the principal change being the addition of ferrous iron with a corresponding development of green color." The now largely replaced barite and a few flecks of muscovite doubtless represent residual minerals of the earlier stage as well.

The formation of the willemite is clearly contemporaneous with some of the chlorite formation. Possibly, since there are clear crystal centers and the dendritic chlorite inclusions, it may have even preceded the chlorite. It certainly continued after the chlorite had ceased to form. On the other hand, colloform surfaces of chlorite, as shown in Figs. 4 and 5, coat early crystals of willemite in all of the druses. There must then have been two stages of willemite formation, the second after the chlorite had ceased forming. The indication is that there was a gap in willemite formation, only one late crystal was found attached as an integral part of an early simple crystal forming a druse wall. Preceding this late willemite stage, however, there was some change in the conditions of iron oxide deposition which resulted in the formation of crystals of specular hematite on the chloritic druse walls. Many of these were later included in the growing willemites.

At the close of the willemite formation there was a distinct change in conditions, which resulted in an etching of willemite and the deposition of late, secondary, sulphides. The prism zones were attacked more weakly than the terminations, many of the latter forms were so rounded that no sharp faces are visible. Less intense etching made the small triangular etch pits seen on *c* in Fig. 5. Succeeding this attack, or possibly simultaneous with it, the sulphides were deposited. The dullness of the galena faces indicates that some later oxidation has altered it and these last solutions may well have formed the threads of serpentinous felt which occupy the centers of some of the pockets.

SUMMARY

The willemite of St. Joseph Lead Company mine at Balmat, St. Lawrence County, New York, is tabular in habit and reasonably constant in appearance, which indicates that it formed under relatively uniform conditions, unlike that of Franklin, New Jersey, which varies greatly in habit and appearance. While comparatively simple in development, good crystals are abundant and some new prism forms were noted. The manner of occurrence, entirely secondary, is, on first thought, unusual, but it is actually very typical of willemite, as the writer expects to emphasize still more strongly in a later paper, summarizing the occurrences of willemite.

REFERENCES

- BROWN, J. S., Structure and primary mineralization of the zinc mine at Balmat, New York; Supergene sphalerite, galena and willemite at Balmat, New York: *Econ. Geology*, **31**, 233-258; 331-354 (1936).
- BUDDINGTON, A. F., Report on the pyrite and pyrrhotite veins in Jefferson and St. Lawrence Counties, New York: *New York State Defense Council, Bull.* **1** (1917).
- MAURICE, M., Über Eisenglanz (Formen und Akzessorien): *Neues. Jahrb. Min., BB* **63**, Abt. A., 279-318 (1932).
- PALACHE, C., *Mineralogical Notes on Franklin and Sterling Hill, New Jersey* (1928).
- PALACHE, C., The minerals of Franklin and Sterling Hill, Sussex County, New Jersey: *U.S.G.S., Prof. Paper* **180** (1935).
- SMYTH, C. H., JR., On a basic rock derived from granite: *Jour. Geol.*, **2**, 667-679 (1894).

THE BARTLETT METEORITE, BELL COUNTY, TEXAS

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HISTORY AND GENERAL FEATURES

The nickel-iron meteorite here described was obtained from Mr. Willard Wiederspahn, a student in the University of Texas, in the fall of 1938. He stated that it was ploughed up in a field by his father "about three years ago" and placed along a fence line.

The field is on the Molly Benson farm, 5 miles west of the town of Bartlett (Lat. 30°50' N., Long. 97°30' W.) in Bell County, Texas. While reading an article on meteorites in a popular magazine, Willard Wiederspahn recalled the "heavy black rock" on the fence line and when he returned to school in the fall of 1938 he brought it to the writer for identification. It is now in the museum of the Department of Geology at The University of Texas. Nothing is known regarding its fall.

The meteorite is roughly rectangular in outline with maximum dimensions as follows: $7\frac{1}{2}$ inches \times $6\frac{1}{2}$ inches \times $3\frac{1}{2}$ inches. The original weight was 8.59 kilograms (18.94 pounds). The specific gravity is 7.444. One edge is more or less rounded while the other is fairly sharp giving the mass, as a whole, a wedge-shaped appearance. One surface is covered by three broad shallow depressions (2 to 3 inches in diameter) while the opposite side has only one such depression (Fig. 1). Pits of small diameter but comparatively deep occur in the depressions, probably formed by the oxidation of troilite nodules. The surface is covered with a coating of oxidation products although several areas of the fusion crust (lower left on Fig. 1) are still visible on the rounded edge. The fusion crust is dull black, relatively smooth and contains many tiny flow lines visible with a lens. Several rather long scratch-like markings occur on the outer surface. These are exceptionally clear where they cut through areas of the fusion crust. In general they have oxidized more readily than the adjoining portions of the mass. These scratch-like markings are believed to be stringers of troilite which were more readily fused than the adjoining material.

STRUCTURE

The specimen was sent to the American Meteorite Laboratory, Denver, Colorado, where it was cut, polished, and etched. It was cut into two nearly equal parts and both surfaces were polished and etched. Two other cuts were made at right angles to the main cut, and to each other, in order to determine the best direction for the main cut and to obtain material for the chemical and spectographic analyses.



FIG. 1. The Bartlett meteorite.



FIG. 2. Polished and etched section of the Bartlett meteorite (medium octahedrite) showing well developed Widmanstätten figures. The prominent plates are kamacite. The direction of the section is shown on Fig. 1 by the two short lines.

The etched surface shows well developed Widmanstätten figures with an octahedral pattern. They consist chiefly of grouped kamacite plates averaging about 1 mm. in width and varying from 1 to 2 cm. in length (Fig. 2). The structure is fairly uniform over the whole mass although in a few places the kamacite plates are much larger (up to 5 mm. in width) and more irregular in shape. In other places the kamacite plates are swollen with rounded ends.

The meteorite is classified as a Medium Octahedrite (Om).

COMPOSITION

Kamacite. In general the mass is composed of grouped kamacite plates averaging about 1 mm. in width and ranging from 1 to 2 cm. in length. The kamacite plates reflect light differently in various areas resulting in a somewhat spotted appearance in reflected light. Separating some of the well defined areas of grouped kamacite plates are more or less irregular bands of kamacite ranging up to 5 mm. in width. In a few places the kamacite plates are more or less rounded, or swollen, and of much smaller size.

Taenite. Surrounding each plate of kamacite is a bright, tin white ribbon of taenite. The bands of taenite are exceedingly small, averaging only a fraction of a millimeter in width. They have a wavy or zigzag appearance, conforming to the variations in width of the kamacite plates. The taenite also penetrates some of the kamacite plates resulting in a much finer structure within the bands.

Plessite. The fields resulting from the areas intervening between the intersection of the kamacite and taenite bands are very sparingly represented, the great majority of the mass being made up of lamellae of kamacite. The few areas present are usually roughly triangular in outline and are filled with dull grayish plessite, surrounded by bands of bright taenite. Most of the plessite areas are less than a millimeter in their long dimension, although a few are larger.

Schreibersite. This mineral is not abundant although a few characteristic areas are present. It occurs in long narrow bands (dark bands in upper right of Fig. 2) having an average width of about 1 mm. and a maximum length of 2 cm. In addition small irregular masses or grains are scattered through the section, ordinarily within bands of kamacite.

Troilite. The troilite occurs as small spheroidal nodules scattered irregularly throughout the meteorite. In general the troilite nodules are in bands of schreibersite. The nodules have been badly decomposed on the polished and etched surface by the acid used in etching. In general, the nodules do not exceed 1 mm. in diameter. However, the polished section cuts through a cavity of irregular outline with a maximum di-

ameter of 1 cm. (extreme left of Fig. 2) which appears to have resulted from the solution of a nodule of troilite. Also a number of pit-like depressions are present on the outer surface, one with a diameter of 1.5 cm. suggests a cavity formerly filled by a troilite nodule. The absence of sulphur in the chemical analysis would indicate that the sample submitted for chemical analysis did not include a troilite nodule.

Lawrencite. The tendency of streaks and fracture lines to rust badly on the polished section together with a trace of chlorine in the analysis suggests the presence of lawrencite.

A chemical analysis of the Bartlett meteorite was made by Dr. F. A. Gonyer and is given below.

Fe	90.41%
Ni	8.88
Co	0.47
P	0.22
Cu	none
Cl	trace
S	none
Mn	none
	<hr/>
	99.98%
Fe ₂ O ₃	1.21 (Scale which was deducted from weight of the sample before calculating the anal- ysis.)

A spectrophotographic analysis of a sample of the Bartlett meteorite, made by Dr. H. A. Wilhelm, is as follows: Fe¹, Ni², Co³, Ge⁴, Cu⁵, Si⁵. Intensities: ¹ strong, ² present, ³ weak, ⁴ trace, ⁵ faint trace.

ACKNOWLEDGMENTS

The chemical analysis was made by Dr. F. A. Gonyer of the Department of Mineralogy and Petrography of Harvard University. The spectrophotographic analysis was made by Dr. H. A. Wilhelm of the Department of Chemistry of Iowa State College. The writer is indebted to Professor F. L. Whitney and Mr. Blake Cockrum of the Department of Geology of The University of Texas for assistance in the photographic work. The cutting, polishing, and etching was done by Mr. H. H. Nininger of the American Meteorite Laboratory, Denver, Colorado.

The chemical and spectrophotographic analyses and the etching of the specimen were made possible by a grant from the Committee on Research Grants and Publications of The University of Texas.

NOTES AND NEWS

NEW DATA ON THE OPTICAL PROPERTIES OF TRIDYMITE

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Unusually large crystals of tridymite occur in the vesicles of a leucocratic andesite at the summit of a conical hill in Sec. 4, T. 23 N., R. 13 E., Plumas County, California. This locality may be reached via the road to Smith Peak branching from the Walker Mine road north of the town of Portola.

The andesite is highly vesicular and consists of phenocrysts of labradorite, 2 mm. to 3 mm. in length, set in a groundmass of andesine laths and scattered magnetite crystals with a colorless glass base. The original ferromagnesian minerals have been completely altered.

Single untwinned crystals of tridymite reach a diameter of 1 mm., and complexly twinned aggregates exceed 2 mm. in diameter. Individual crystals are thin pseudohexagonal basal tablets with ridges on the basal plane extending from the center to the intersections of the prisms. All of the common forms and twinning habits are present. Aragonite type of twinning and complex lamellar twinning analogous to that in leucite are both shown on the basal plane.

All crystals are optically biaxial with the optic plane normal to the basal plane and a face in the prism zone. Assuming the customary orientation with the optic plane as (100), then $X=b$, $Z=c$. The optic sign is positive. The usually assumed orthorhombic character is not disproved by any observations.

2V was measured with the universal stage on basal plates mounted in balsam. Values determined from the measurement of fifteen crystals range from 66° to 90° . In nine of the fifteen crystals measured 2V is between 80° and 89° . Measurements on separate twin parts of the same crystal yielded different values as is indicated by the following pairs: 77° – 81° and 75° – 84° . Repeated measurements on the same twin sector gave consistent results.

The indices of refraction as determined in oils with sodium light are as follows:

$$\alpha=1.478\pm$$

$$\beta=1.479+$$

$$\gamma=1.481\pm$$

The probable limits of error are ± 0.001 . An independent determination of the double refraction in a thin section 120 microns in thickness gave a value of 0.0025 ± 0.0002 .

The indices of refraction are higher, the size of 2V is larger, and the double refraction is lower than some published values. Various published data are not in agreement and this is perhaps due to the difficulty of working with the usually very small crystals. The large variation in the size of 2V is probably due to uneven strain on inversion from the higher temperature hexagonal form. It is believed that the data given here are unusually good in view of the greater ease of handling and certainty of determination of the larger crystals from this locality.

A MOUNT FOR THE UNIVERSAL STAGE STUDY
OF FRAGILE MATERIALS

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The accessory here described is intended for use in the immersion method of grain study on the universal stage. It serves two purposes: (1) to minimize strains sometimes introduced in grains by the pressure from a hemisphere, which strains might cause changes in the optical properties or result in the shattering of fragile grains (e.g., organic crystal fragments), and (2) to facilitate the controlled movement of a grain (e.g., centering) after a mount is made and is ready for study. The accessory is a metal slide which acts as a retaining cell for the mount. A single grain or crystal is mounted in the immersion liquid between two cover glasses which are held in this retaining cell. The metal slide supports the weight of the hemisphere and its extension permits movement of the entire unit for the centering of the grain.

Slide: The metal slide, whose details are shown in Fig. 1, is turned out of sheet brass on a lathe. The central opening is slightly larger than the diameter of the cover glasses (clearance not over 0.15 mm.). The cover glasses must neither bind in the opening nor shift to a large extent when the stage is tilted. The shoulder encircling the central opening is divided into concentric rings to improve the retention of the immersion liquid.

The thickness of the slide at the shoulder will depend upon the average size and uniformity of the grains studied. The surface of the upper cover glass must be even with, or slightly below, the top of the brass slide. In this way the grain is held in place by the weight of the cover glass augmented by little or no pressure from the hemisphere. The dimensions shown in Fig. 1 have proven generally satisfactory. If applicability to greater variation in grain size is desired, the thickness may be that of three No. 2 cover glasses and the grains accommodated by appropriate combinations of No. 1 and No. 2 cover glasses.

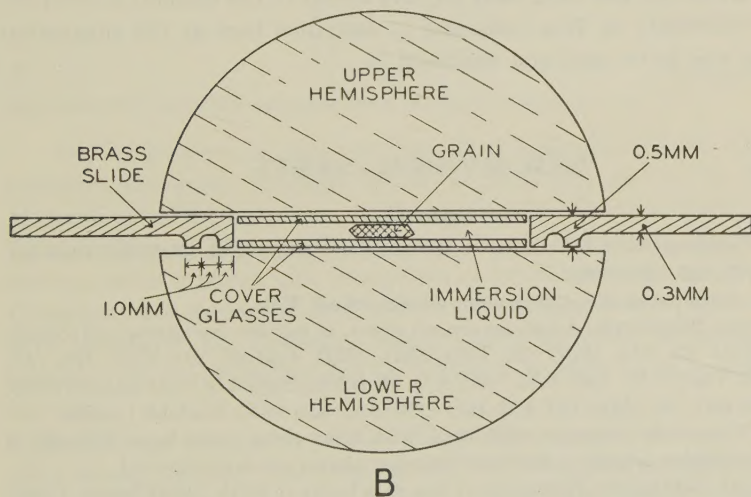
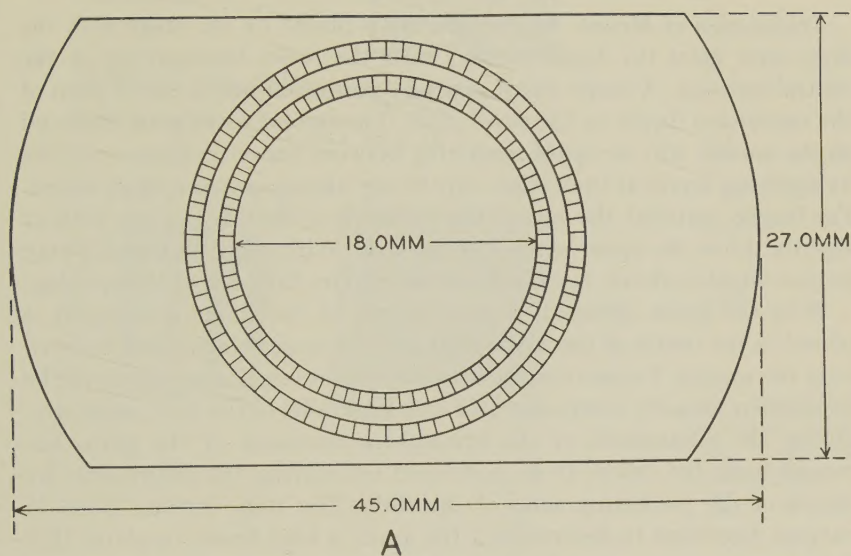


FIG. 1. A mount for fragile grains.

- A. Brass slide, view of under side, showing retaining shoulder.
 B. Slide and mount, cross section, showing the relative positions of hemisphere, cover glasses, grain and brass slide. The vertical scale has been increased four times to show detail.

Preparation of Mount: The brass slide is placed on the stage with the first cover glass (in liquid contact with the lower hemisphere) in the central opening. A *single* small grain is introduced into a small drop of the immersion liquid on the cover glass. The second cover glass is placed on the mount. Any air space remaining between the cover glasses is filled by applying liquid at their edge, care being taken to avoid a large excess. For fragile material the top of the cover glass should be even with or slightly below the upper surface of the slide. With other material it may project slightly above, but must still be held by the edge of the opening.

With the grain centered, a drop or two of the immersion liquid is placed in the center of the cover glass and the upper hemisphere lowered onto the mount. To prevent the introduction of large bubbles, move the hemisphere steadily downward and keep it parallel to the slide, especially during the adjustment of the hemisphere fasteners. If the grain has moved from the center it is recentered by moving the entire unit by means of the projecting arms of the slide. The stage is then tilted in various directions to determine if the grain is held firmly in place. If it is not, a new mount must be made either with a larger grain, additional cover glass thickness, or a different slide.

This technique has been used for over a year in the mineral laboratory at the University of Wisconsin and is described here at the suggestion of those who have used and endorsed it.

NEW MINERAL NAMES

Lovozerite

V. I. GERASSIMOVSKY, Lovozerite—a new mineral. *Compt. Rend. (Doklady) Acad. Sci. U.R.S.S.*, **25**, 753–756 (1939).

NAME: From the locality, the Lovozero alkaline massif, Kola.

CHEMICAL PROPERTIES: A hydrous zircono-silicate of calcium, manganese and sodium. $(H, Na, K)_2O \cdot (Ca, Mn, Mg)O \cdot (Zr, Ti)O_2 \cdot 6SiO_2 \cdot 3H_2O$. Analysis: SiO_2 52.12, TiO_2 1.02, ZrO_2 16.54, Th_2O_3 0.56, Al_2O_3 0.40, Fe_2O_3 0.72, MnO 3.46, MgO 0.76, CaO 3.34, SrO 0.06, Na_2O 3.74, K_2O 1.90, $H_2O + 110^\circ$ 8.62, $H_2O - 110^\circ$ 6.41; sum 99.65. Insoluble in acids.

B. B. Fuses easily to opaque white bead. With borax yields purple bead. With salt of phosphorus yields a greenish-yellow bead when hot, almost colorless when cold.

PHYSICAL AND OPTICAL PROPERTIES: Color dark brown to black. Streak brown. Luster resinous. Opaque. Fracture uneven to conchoidal. $H. = 5$. $G. = 2.384$.

Uniaxial, negative. $\omega = 1.561$, $\epsilon = 1.549$. Color light pink, pleochroism feeble. Polysynthetic twinning frequent.

OCCURRENCE: Found in the Lovozero alkaline massif as one of the rock-forming or secondary minerals in certain porphyritic luyavrites, associated with murmanite, lamprophyllite, amphibole, nepheline, etc. Some of the lovozerite is considered as a primary mineral, some as secondary, derived from eudialyte.

W. F. FOSHAG